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VARIABILITY AND SENSITIVITY COUPLED MISED LAYER-ACOUSTIC MODEL SYSTEMS

Rory H. Fisher

NPS68-81-002

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

Variability and Sensitivity
of
Coupled Mixed Layer-Acoustic Model Systems

by

Rory H. Fisher

March 1981

Thesis Advisors: Calvin R. Dunlap
R. W. Garwood, Jr.

Approved for public release, distribution unlimited

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The capability to accurately model the thermal structure was reviewed with the following results. No significant correlation was observed between the EOTS model and the actual BT mixed layer depths while there appeared to be a strong positive correlation between the ODT model (driven by atmospheric forcing) and the BT mixed layer depths. Moreover, a possible lag of two days was observed in the EOTS model mixed layer depth relative to the observed mixed layer depth time series.

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Variability and Sensitivity of Coupled Mixed Layer-Acoustic Model Systems

by

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Lieutenant, United States Navy
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Submitted in partial fullfillment of the
requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS TECHNOLOGY

from the

NAVAL POSTGRADUATE SCHOOL
March 1981

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This study is the first reported analysis of coupled mixed layer-acoustic model systems. The analysis emphasizes the performance of the combined systems rather than the acoustic or ocean models separately. Acoustic variability of the coupled model systems was studied in terms of the median detection range (MDR). Synoptic time variations of MDR as a function of figure of merit, frequency, and receiver depth were analyzed during the month of May 1980 at OWS "Papa" in order to provide a better insight into the operational capabilities of model systems to accurately represent the actual oceanic variability. The results of this limited analysis revealed that the model systems displayed more day-to-day acoustic (MDR) variability than did direct environmental input (BT).

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TABLE OF CONTENTS

I. INTRODUCTION ---------- 15

A. PURPOSE ---------- 15

B. IMPORTANCE ---------- 15

C. METHODOLOGY ---------- 15

D. DATA SOURCE: OWS "PAPA" ---------- 33

II. MODEL THEORY ---------- 37

A. FACT MODEL ---------- 37

1. Limitations ---------- 39

a. Low Frequency ---------- 40

b. Half Channel ---------- 40

c. Surface Duct Propagation ---------- 41

B. ONE DIMENSIONAL THERMODYNAMICS (ODT) MODEL -- 41

C. EOTS MODEL ---------- 43

III. MODEL SYSTEMS AND EXPERIMENTAL RESULTS --------- 46

A. EOTS-FACT ACOUSTIC ANALYSIS ---------- 47

B. ODT-FACT ACOUSTIC ANALYSIS ---------- 59

C. BT-FACT ACOUSTIC ANALYSIS ---------- 68

IV. DISCUSSION OF RESULTS ---------- 81

A. ACOUSTIC COMPARISON ---------- 81

1. FOM Effects ---------- 81

2. Frequency Effects ---------- 86

3. Receiver Depth Effects ---------- 87

B. THERMAL STRUCTURE COMPARISON ---------- 92
1. Mixed Layer Depth ---------- 95
2. Event Analysis ---------- 99
3. Sea Surface Temperature (SST) ---------- 100
4. Below Layer Gradient ---------- 100
V. CONCLUSIONS ---------- 108
APPENDIX A (OPERATIONAL AND MODELING APPLICABILITY) ---- 114
REFERENCES ---------- 119
INITIAL DISTRIBUTION LIST ---------- 121

LIST OF TABLES

Table		Page
I.	Mean and standard deviation of the median detection range (MDR) for all phases of the analysis.	88
II.	Minimum and maximum values (range) of the median detection range (MDR) for all phases of the analysis.	89
III.	Mean and standard deviation of the median detection range for selected phases of the analysis.	110

LIST OF FIGURES

Figure		Page
1.	DBPLOT output from FNOC ----------	17
2.	EOTS climatology for the month of May ---------- (Thermal structure and sound velocity profile)	22
3.	Solar radiation, total heat flux, and wind ----- speed values input to ODT model.	24
4.	Measurement uncertainty for the ODT-FACT ------- analysis for FOM of 74-76 dB, 50 Hz, and receiver depth of 200 feet.	25
5.	Same as Figure 4 except frequency of 300 Hz.----	25
6.	Same as Figure 4 except FOM of 79-81 ----------	26
7.	Same as Figure 6 except frequency of 300 Hz.----	26
8.	Measurement uncertainty for the EOTS-FACT ------ analysis for FOM of 79-81 dB, frequency of 50 Hz, receiver depth of 200 feet.	27
9.	Same as Figure 8 except frequency of 300 Hz. ---	27
10.	Same as Figure 8 except FOM of 74-76 dB. -------	28
11.	Same as Figure 10 except frequency of 300 Hz.---	28
12.	Measurement uncertainty for the BT-FACT analysis- for FOM of 79-81 dB, 50 Hz, and receiver depth of 200 feet.	29
13.	Same as Figure 12 except frequency of 300 Hz.---	29
14.	Same as Figure 12 except FOM of 74-76 dB. ------	30
15.	Same as Figure 14 except frequency of 300 Hz.---	30
16.	Measurement uncertainty for the BT-FACT -------- analysis for FOM of 79-81 dB, frequency of 300 Hz, and receiver depth of 700 feet.	31
17.	Same as Figure 16 except for EOTS-FACT analysis.-	32

Figure

18. Same as Figure 16 except for ODT-FACT analysis.-- 32

19. Location of Ocean Station "P". ---------- 34

20. Median Detection Range (MDR) versus time for ---- 48
the EOTS-FACT analysis: FOM of 70 dB, receiver depth of 200 feet, frequency range of 25 Hz, 50 Hz, 150 Hz, 300 Hz.

21. Same as Figure 20 except receiver depth of 700 -- 48
feet.

22. Same as Figure 20 except FOM of 75 dB. ---------- 49

23. Same as Figure 22 except receiver depth of ------ 49
700 feet.

24. Same as Figure 24 except FOM of 80 dB. ---------- 50

25. Same as Figure 24 except receiver depth of ------ 50
700 feet.

26. Median Detection Range (MDR) versus time for ---- 52
the EOTS-FACT analysis: Comparison of 200 foot receiver to 700 foot receiver at 25 Hz at FOM of 80 dB.

27. Same as Figure 26 except frequency of 50 Hz.----- 52

28. Same as Figure 26 except frequency of 150 Hz. --- 53

29. Same as Figure 26 except FOM of 300 Hz. --------- 53

30. Same as Figure 26 except FOM of 75 dB.---------- 54

31. Same as Figure 30 except frequency of 50 Hz.----- 54

32. Same as Figure 30 except frequency of 150 Hz.---- 55

33. Same as Figure 30 except frequency of 300 Hz. --- 55

34. Median Detection Range (MDR) versus time for ---- 56
EOTS-FACT analysis: Comparison of FOM's of 70 dB, 75 dB, 80 dB, frequency of 25 Hz, receiver depth of 200 feet.

35. Same as Figure 34 except frequency of 50 Hz.----- 56

36. Same as Figure 34 except frequency of 150 Hz.---- 57

37. Same as Figure 34 except frequency of 300 Hz.---- 57

38. Same as Figure 34 except receiver depth of 700--- 58
feet.

39. Same as Figure 38 except frequency of 300 Hz.---- 58

40. Median Detection Range (MDR) versus time for ---- 60
the ODT-FACT analysis: FOM of 70 dB, receiver
depth of 200 feet, frequency range of 25 Hz,
50 Hz, 150 Hz, 300 Hz.

41. Same as Figure 40 except FOM of 75 dB.---------- 61

42. Same as Figure 41 except receiver depth of ------ 61
700 feet.

43. Same as Figure 40 except FOM of 80 dB. ---------- 62

44. Same as Figure 43 except receiver depth of ------ 62
700 feet.

45. MDR versus time for the ODT-FACT analysis: ------ 64
Comparison of 200 foot receiver to 700 foot
receiver at 25 Hz at an FOM of 80 dB.

46. Same as Figure 45 except frequency of 50 Hz. ---- 64

47. Same as Figure 45 except frequency of 150 Hz.---- 65

48. Same as Figure 45 except frequency of 300 Hz.---- 65

49. Same as Figure 45 except at an FOM of 75 dB.----- 66

50. Same as Figure 49 except frequency of 50 Hz.----- 66

51. Same as Figure 49; frequency of 150 Hz.---------- 67

52. Same as Figure 49; frequency of 300 Hz.---------- 67

53. MDR versus time for the ODT-FACT analysis: ------ 69
Comparison of FOM's of 70 dB, 75 dB, 80 dB,
for frequency of 25 Hz, receiver depth of
200 feet.

54. Same as Figure 53; frequency of 50 Hz. ---------- 69

55. Same as Figure 53; frequency of 150 Hz.---------- 70

56. Same as Figure 53; frequency of 300 Hz. --------- 70

57. Same as Figure 53 except receiver depth of 700 feet, frequency of 50 Hz. --- 71

58. Same as Figure 57 except frequency of 300 Hz. ---- 71

59. MDR versus time for the BT-FACT analysis: FOM of 70 dB, receiver depth of 200 feet, frequency range of 25 Hz, 50 Hz, 150 Hz, 300 Hz. ------- 73

60. Same as Figure 59 except FOM of 75 dB. ---------- 74

61. Same as Figure 59 except FOM of 80 dB. ---------- 74

62. MDR versus time for BT-FACT analysis: Comparison of 200 foot receiver with 700 foot receiver for FOM of 75 dB, frequency of 50 Hz. ---------- 75

63. Same as Figure 62 except FOM of 80 dB. ---------- 75

64. MDR versus time for BT-FACT analysis: FOM of 80 dB, receiver depth of 700 feet, frequency range of 25 Hz, 50 Hz, 150 Hz, 300 Hz. ------- 77

65. Same as Figure 64 except at an FOM of 75 dB. ----- 77

66. MDR versus time for the BT-FACT analysis: Comparison of FOM's of 70 dB, 75 dB , 80 dB, for 200 foot receiver at 50 Hz. ------- 78

67. Same as Figure 66 except frequency of 300 Hz. ---- 78

68. Same as Figure 66 except receiver depth of 700 feet. --- 79

69. Same as Figure 68 except frequency of 300 Hz. ---- 79

70. Median Detection Range (MDR) versus time: Comparison of EOTS-FACT to BT-FACT for frequency of 50 Hz and 300 Hz at a receiver depth of 200 feet. ------- 82

71. MDR versus time: Comparison of EOTS-FACT and ODT-FACT to BT-FACT at 50 Hz and FOM of 75 dB. ------- 84

72. Same as Figure 71 except frequency of 300 Hz. ---- 84

73. Thermal structure and sound velocity profile --- 93
envelopes for the BT-FACT system.

74. Thermal structure and sound velocity profile --- 93
envelopes for the EOTS-FACT system.

75. Thermal structure and sound velocity profile --- 93
envelope for the ODT-FACT system.

76. Mixed Layer Depth versus time for BT-FACT, ----- 94
ODT-FACT and EOTS-FACT systems.

77. Mixed Layer Depth versus time: Comparison of -- 96
ODT to EOTS, ODT shifted forward one day.

78. Same as Figure 77, except ODT shifted forward -- 96
two days.

79. Same as Figure 77, except ODT shifted forward -- 96
three days.

80. EOTS grid structure location in comparison to -- 98
OWS Papa.

81. Sea Surface Temperature versus time: Comparison- 101
of ODT and EOTS SST to the BT SST.

82. Below Layer Gradient (measured from mixed layer- 103
to a depth of 200 meters) versus time:
Comparison of ODT and EOTS with the actual BT.

83. Below Layer Gradient (measured from the surface- 104
to 100 meters) versus time: Comparison of ODT
and EOTS with the actual BT.

84. "Average" thermal structure and sound velocity-- 107
profiles for May 1980, for BT, ODT, and EOTS
analyses.

85. MDR versus time: Comparison of EOTS-FACT and -- 109
ODT-FACT to BT-FACT for an FOM of 80 dB at
50 Hz, for a receiver depth of 200 feet.

86. Same as Figure 85 except frequency of 300 Hz.--- 109

GLOSSARY

1. Mixed Layer Depth (MLD): The shallowest depth below the surface at which the temperature gradient exceeds $2^{o}F/100$ feet.
2. Sonic Layer Depth (SLD): The shallowest point on the sound velocity profile that is a maximum. For half channel cases, SLD is at the surface.
3. Coupled model system: Any system where both a thermal model and an acoustic model are used in conjunction to produce an output product.
4. Median Detection Range: The range that produces a 50% probability of detection; found from the sonar equation, setting signal excess equal to zero.
5. BT - An instrument used for bathythermographic observations as well as the observed profile itself (depending on context).
6. EOTS - Expanded Ocean Thermal structure, present ocean thermal structure analysis system in use at Fleet Numerical Oceanography Center.
7. ODT - One Dimensional Thermodynamic Model developed at the Naval Postgraduate School.
8. FACT - Fast asynoptic coherent transmission loss acoustic model.

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I. INTRODUCTION

A. PURPOSE

The purpose of this thesis is to investigate the sensitivity of coupled mixed layer-acoustic model systems to variations in figure of merit, frequency, and receiver depth. The sensitivity and variation in time of combined systems is studied in order to gain a better insight into the operational capabilities of present mixed layer-acoustic modeling techniques.

B. IMPORTANCE

The capability to predict acoustic parameters directly affects virtually all aspects of acoustic antisubmarine warfare from planning to execution. Even though acoustics from the viewpoint of ASW is not an exact science, it is imperative to understand the capabilities and limitations of the science. Acoustic and thermal structure modeling is one attempt to understand the science, and will be the central focus of this study.

C. METHODOLOGY

Whereas previous analyses [Johnson, 1977 and Harvey, 1972] of both thermal and acoustic models have been limited in scope to a particular thermal or acoustic model under

observation, this study investigates the variability and sensitivity of coupled mixed layer-acoustic model systems.

This study made in May 1980 consisted of two experiments. The first involved the use of a currently operational system in use at the Fleet Numerical Oceanography Center (FNOC) and the second experiment consisted of using a completely different thermal model developed at the Naval Postgraduate School. Both experiments were run for a common point (Ocean Weather Station Papa) and all data was processed at the Fleet Numerical Oceanography Center. All data was obtained in the form of the FNOC DBPLOT product (Fig. 1). For the passive acoustic analysis undertaken, the Fast Asymptotic Coherent Transmission Loss (FACT) model was used to obtain acoustic data. The DBPLOT output provides the FACT propagation loss information represented as a function of range. It also displays the corresponding thermal profile and sound velocity profile input to the FACT model (Fig. 1).

To date, sensitivity analyses of both thermal and acoustic models have been conducted in a "stand alone" mode. A sensitivity analysis consists of varying input parameters one at a time while holding other parameters constant. The output product is then analyzed and compared with actual observations where possible. The comparison and analysis process to date has been characterized as a "snapshot" of a dynamic process.

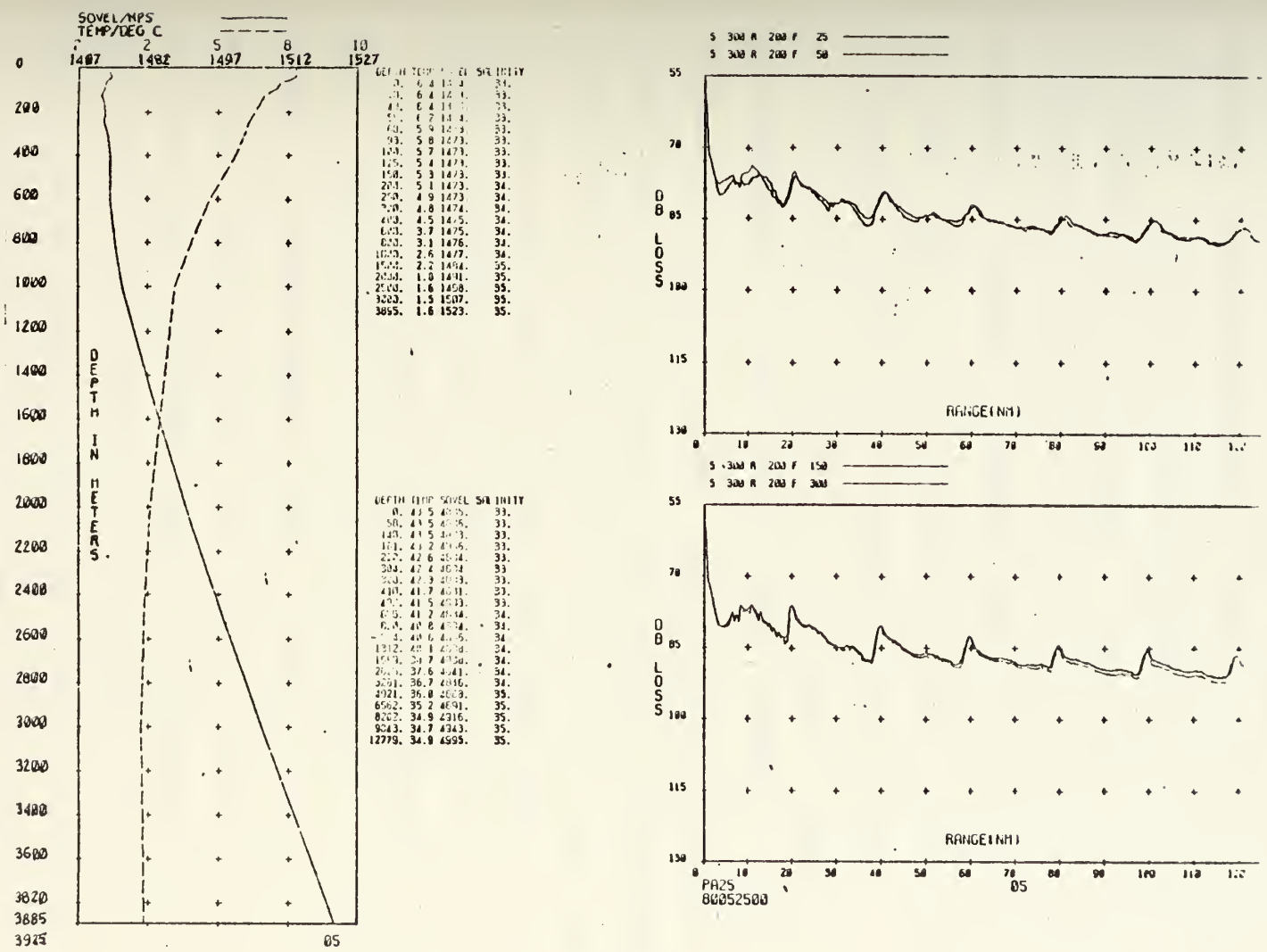


Figure 1

DBPLOT Output from FNOC

From an operational point of view the output products used by the fleet are generally a result of coupled model systems representing merely a single look at a dynamic process. Analysis of these snapshots revealed that based on a single point observation, it was difficult at best to make absolute judgements as to quality, accuracy, and validity of results. However when the individual snapshots were put together and reviewed in a time series, the resulting dynamic variability warranted investigation.

The acoustic output of the two coupled model systems was compared with the output of the reference system in both thermal and acoustic terms. The reference system or ground truth chosen was the actual time series of bathythermographs (BT's) taken at Ocean Weather Station (OWS) Papa from 1 May to 31 May 1980, as the thermal structure input to the FACT model. Hereafter, this system is referred to as BT-FACT.

There are two ongoing philosophies regarding the treatment of BT soundings that must be discussed. The first school of thought suggests that an actual BT, even if it is accurate, may not reflect the thermal structure of the <u>area</u> of operations. Therefore the BT is weighted as an input, then merged with climatology to represent the "real-time" profile to be input to the acoustic model. The other philosophy asks the question that if the BT taken is not to be believed or utilized as the most current information, then why take the trouble to drop a BT in the first place?

There may be merit in either philosophy, depending upon the temporal and spatial scales of the anomalous part of the thermal structure. Nevertheless, based on the information available, the actual BT was used as the control for all analyses.

The FACT model in this study was treated as a "black box" as no overt tuning of parameters was done throughout the analysis. Wind speed and wave height, parameters which slightly affect only the surface duct mode, change automatically as the Expanded Ocean Thermal Structure (EOTS) fields change. However as wind speed varied from 0 to 30 knots and wave height ranged between 0 and 40 feet, there were no significant acoustic differences apparent when six representative thermal profiles were input to the FACT model. Most of the major differences in the output products of the model systems are therefore basically attributable to differences in the input thermal structure. This allowed for an indepth analysis of the output products of the model systems as well as providing an insight into the cause of most differences.

The two model systems used in the experiements were (1) the Expanded Ocean Thermal Structure (EOTS-FACT) and (2) the One Dimensional Thermodynamic model (ODT-FACT). The EOTS-FACT system was chosen because it is presently the predominant passive model system used by FNOC. The particular

ODT model employed represents the state-of-the-art in ocean mixed layer models.

The EOTS-FACT model runs were made at FNOC using actual synoptic information. The output product is reproducible in that identical results would be obtained if a request were made by an operational fleet unit for OWS Papa during the experimental period of 1-31 May 1980.

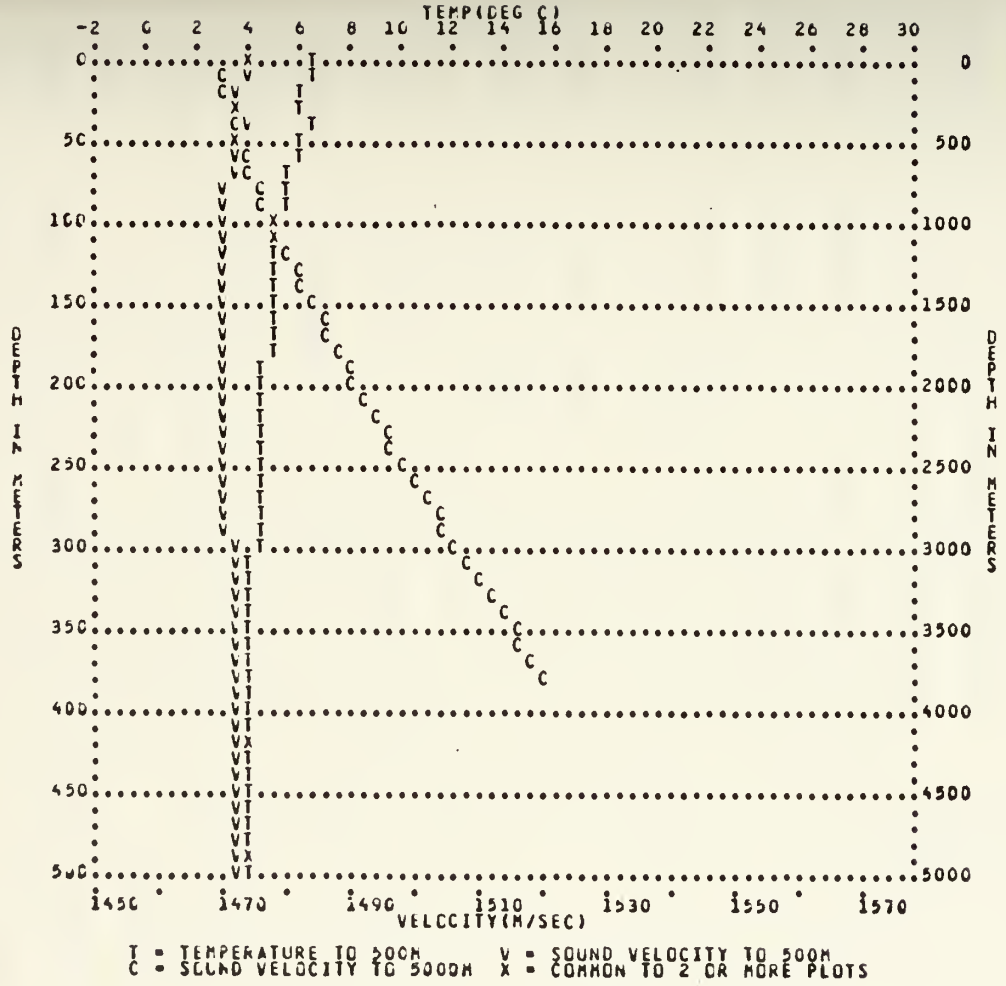
It is important to realize that there are two data bases in use at FNOC: historical synoptic and climatological. Historical synoptic fields are an attempt to recreate the conditions for a precise day while climatology is a many-year average of monthly periods for specific regions of the ocean. The data set for this investigation comes from the historical synoptic fields.

A second coupled model system was run concurrently at OWS Papa. Using the One Dimensional Thermodynamic model coupled with the FACT model (ODT-FACT), the operational product DBPLOT was output as before. The atmospheric forcing fields of marine winds, total heat flux and solar radiation were taken from the FNOC library (catalogued A-11, A-17, A-28, A-29) and modified by a computer process [Gallacher, 1978] to give hourly heat and momentum flux values. The ODT model was initialized isothermal to a depth of 125 meters in order not to bias the ODT model to the actual bathythermograph (BT) or the EOTS thermal structure. The interpolated meteorological fields were then used as the

boundary conditions to drive the ODT model. The resultant model-computed thermal structure was saved every twelve hours for the entire period 1-28 May 1980. These thermal profiles covered from the surface to a depth of 200 meters with a one meter resolution. The profiles were smoothly matched with the climatology base for temperature below 200 meters before being provided as an input to the FACT model.

The merging of both the ODT thermal structure and the BT (reference) from the surface to the bottom, was accomplished using the EOTS climatology (Fig. 2) below 400 meters. The matching procedure involved maintaining the shape ($\partial T/\partial Z$) of the upper thermal profile and disregarding the absolute temperature values. For the ODT model, the matching process required the entire upper thermal profile (< 200 meters) to be decreased by $.5^{o}C$, keeping constant the shape of the profile. The blending of the reference BT to the EOTS climatology required only a smooth merger of the last observed depth (around 320 meters) with the EOTS climatology at 400 meters. Acknowledging the fact that the merging problem in itself is an area that warrants further study, the vertical gradient of the ODT profile was not changed by the matching procedure -- a requirement judged to be most important.

The atmosphere forcing functions of marine winds, solar radiation and total heat flux that were obtained from FNOC had to be processed by a complex computer routine (Gallacher, 1978). This was necessary in order to convert this data to



DEPTH	TEMP(DEG C)	SALINITY	VEL(M/SEC)
0.00	6.64	32.59	1474.46
19.34	6.23	32.61	1473.18
44.34	6.26	32.72	1473.86
56.84	5.84	32.78	1472.46
69.34	5.54	32.84	1471.55
44.34	5.22	32.97	1470.86
100.00	5.20	33.00	1470.89
125.00	5.04	33.23	1470.96
150.00	4.93	33.47	1471.24
200.00	4.67	33.75	1471.37
250.00	4.42	33.81	1471.24
300.00	4.27	33.86	1471.52
400.00	4.01	34.00	1472.27
600.00	3.68	34.19	1474.44
800.00	3.29	34.31	1476.30
1000.00	2.67	34.38	1477.90
1500.00	2.40	34.53	1484.47
2000.00	1.97	34.59	1491.19
2500.00	1.72	34.63	1496.67
3000.00	1.59	34.66	1500.80
3695.06	1.63	34.68	1502.71
DEPTH(F)	TEMP(DEG F)	SALINITY	VEL(F/SEC)
0.00	43.95	32.59	4837.47
63.45	43.21	32.61	4833.27
145.47	43.27	32.72	4835.50
166.48	42.51	32.78	4830.91
227.49	41.97	32.84	4827.92
309.51	41.40	32.97	4825.66
328.06	41.36	33.00	4825.79
410.10	41.07	33.23	4826.05
492.13	40.87	33.47	4826.90
656.17	40.41	33.75	4827.33
820.21	39.96	33.81	4826.90
964.25	39.69	33.88	4827.62
1312.34	39.22	34.00	4830.28
1968.50	38.62	34.19	4837.40
2624.67	37.92	34.31	4843.50
3280.84	37.17	34.38	4846.75
4921.26	36.32	34.53	4870.31
6561.68	35.55	34.59	4892.22
8202.10	35.10	34.63	4916.90
9842.52	34.86	34.66	4943.57
12778.87	34.93	34.68	4995.77

Figure 2

EOTS Climatology for the month of May
(thermal structure and sound velocity profile)

hourly intervals - the ODT model time step. The resulting hourly flux values are shown in figure 3.

The acoustic measure of effectiveness chosen for the analyses was the median detection range (MDR), used by ASW fleet units (VP, VS, TASS) as a tactical aid or sonobuoy spacing parameter. The thermodynamic parameters discussed are mixed layer depth, below layer gradient and sea-surface temperature. The synoptic variability of median detection range is the major point of analysis while discussion of the variability of the thermal parameters yields an insight into the reasons for any observed acoustic variability. The primary method of analysis consisted of time series histories of each parameter in order to determine if the model systems were accurately depicting the variability of the ocean. Most of the acoustic analysis involved extracting data from propagation loss profiles (DBPLOT) entered by a reference figure of merit (FOM). Because of the inherent inaccuracies involved in such a process, an error analysis was done in order to establish accuracy limitations for the entire analysis. Figures 4 through 18 display the limiting cases (50 Hz - 300 Hz) for the three different analyses. The error or uncertainty analysis was accomplished by entering the propagation loss curves at a FOM of 75±1 dB and 80±1 dB. Therefore, the graphs (Figs. 4-18) visually give insight into the errors in MDR that could possible accrue due to a resolution error of ±1 dB in the analysis process. The error analysis shows a

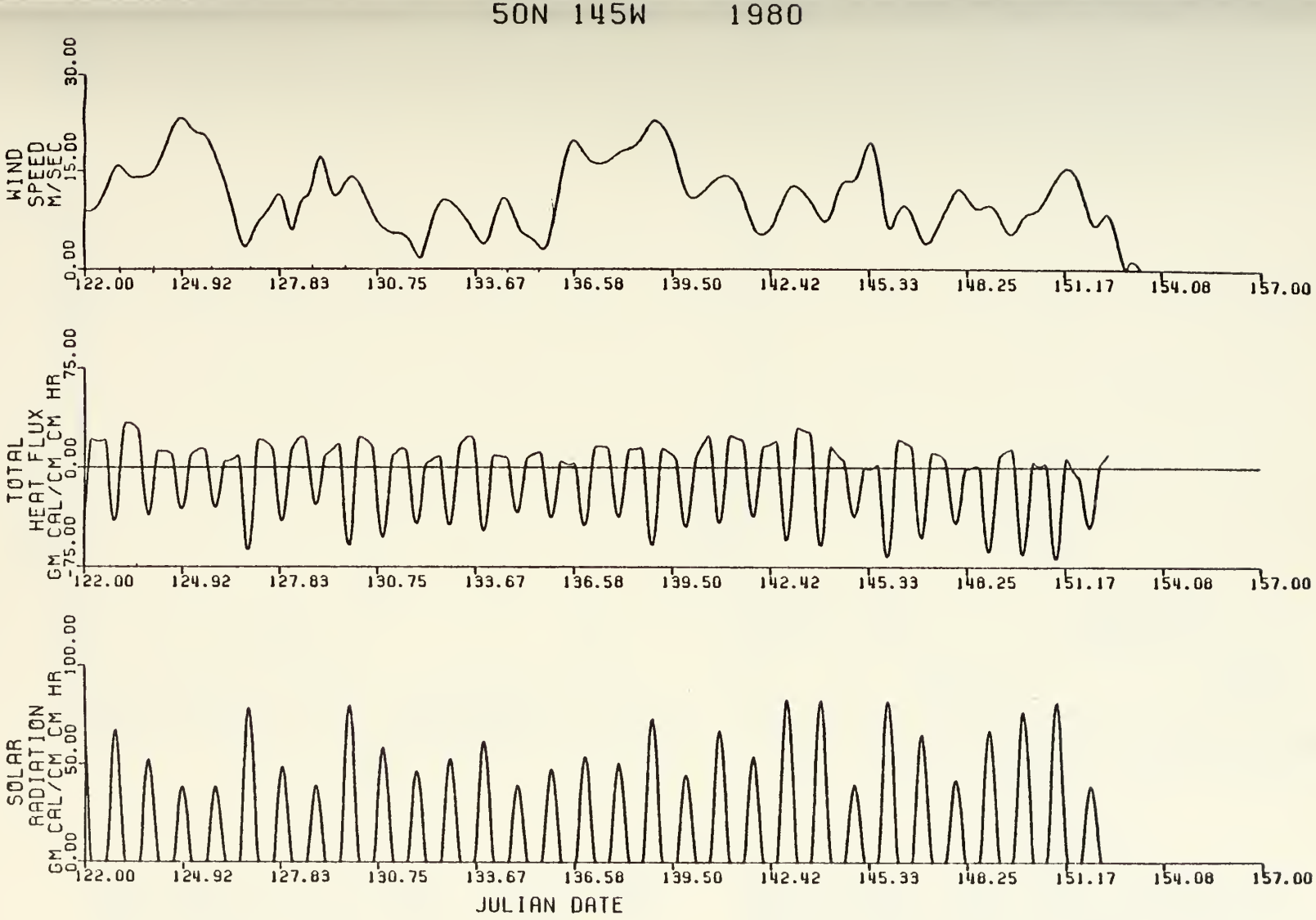


Figure 3

Solar radiation, total heat flux, and wind speed values input to the ODT model

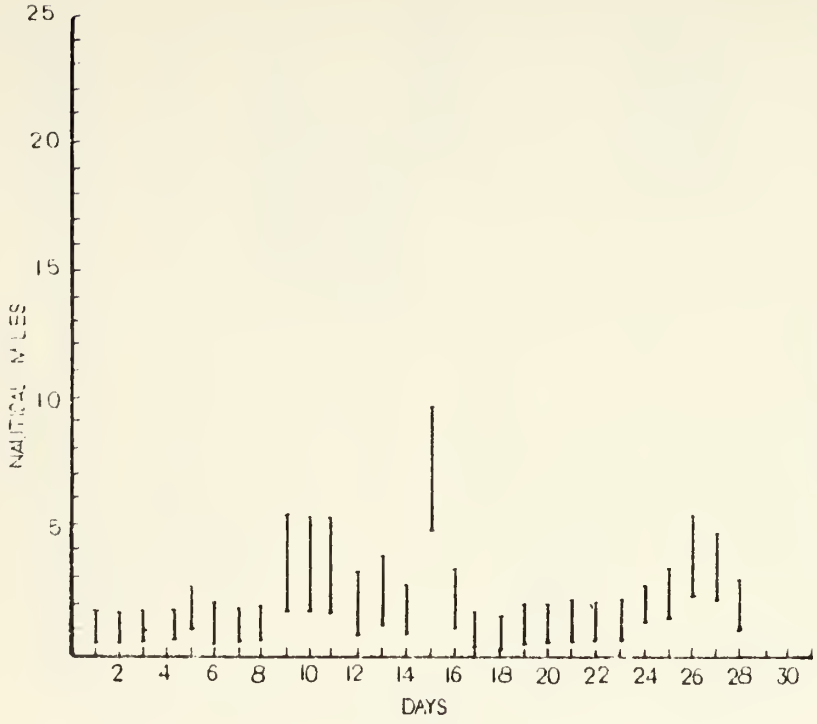


Figure 4

Measurement uncertainty for the ODT-FACT analysis for FOM of 75±dB, 50Hz, and receiver depth of 200 feet.

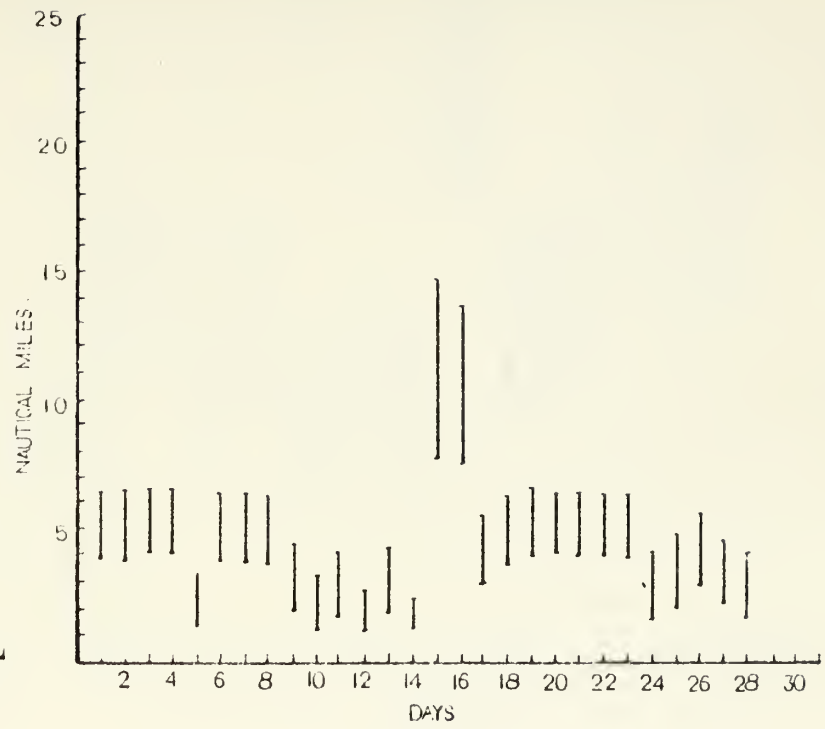


Figure 5

Measurement undertainty for the ODT-FACT analysis for FOM of 75±dB, 300 Hz and receiver depth of 200 feet.

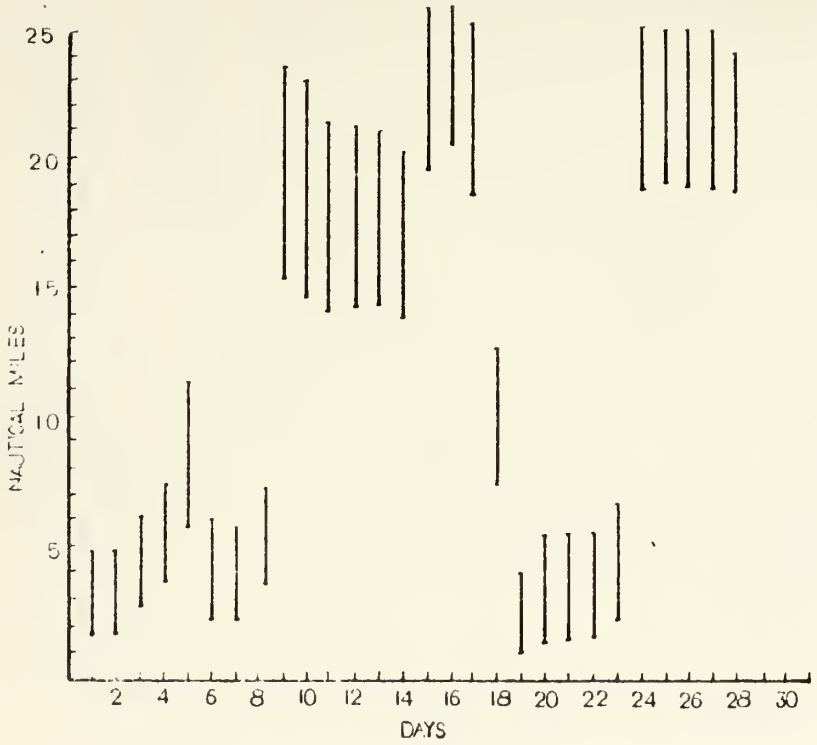


Figure 6

Measurement uncertainty for the ODT-FACT analysis for FOM of 80±1 dB, 50Hz and receiver depth of 200 feet.

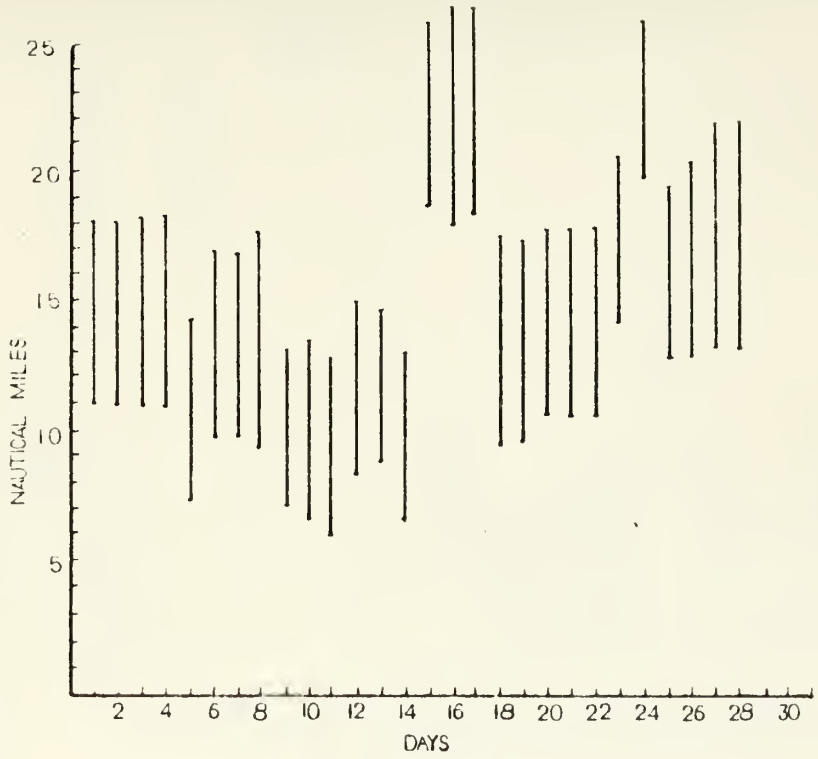


Figure 7

Measurement uncertainty for the ODT-FACT analysis for FOM of 80±1 db, 300 Hz, and receiver depth of 200 feet.

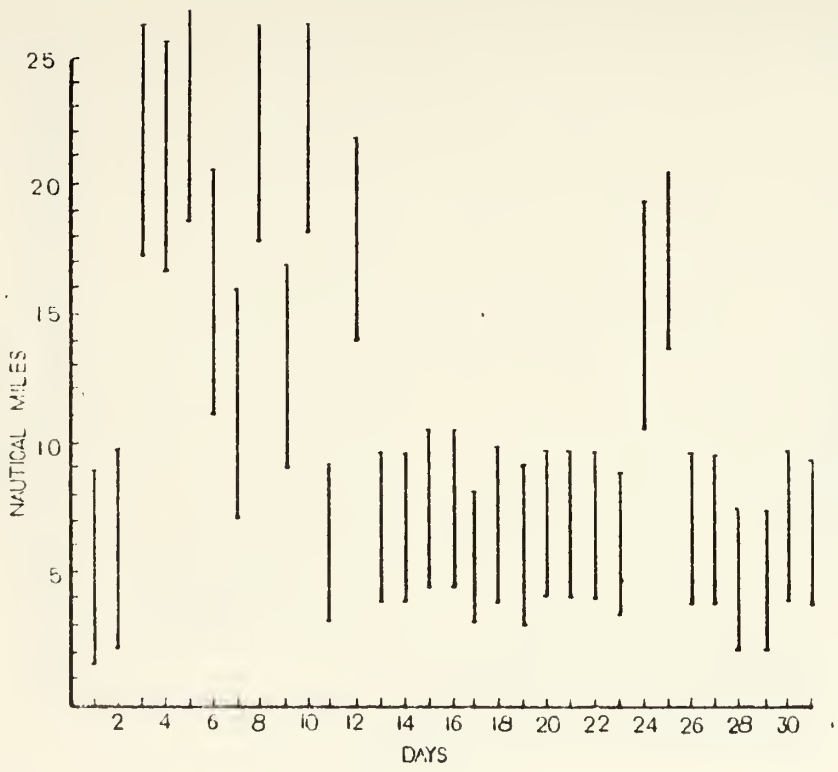


Figure 8

Measurement uncertainty for the EOTS-FACT analysis for FOM of 80±1 dB, 50Hz and receiver depth of 200 feet.

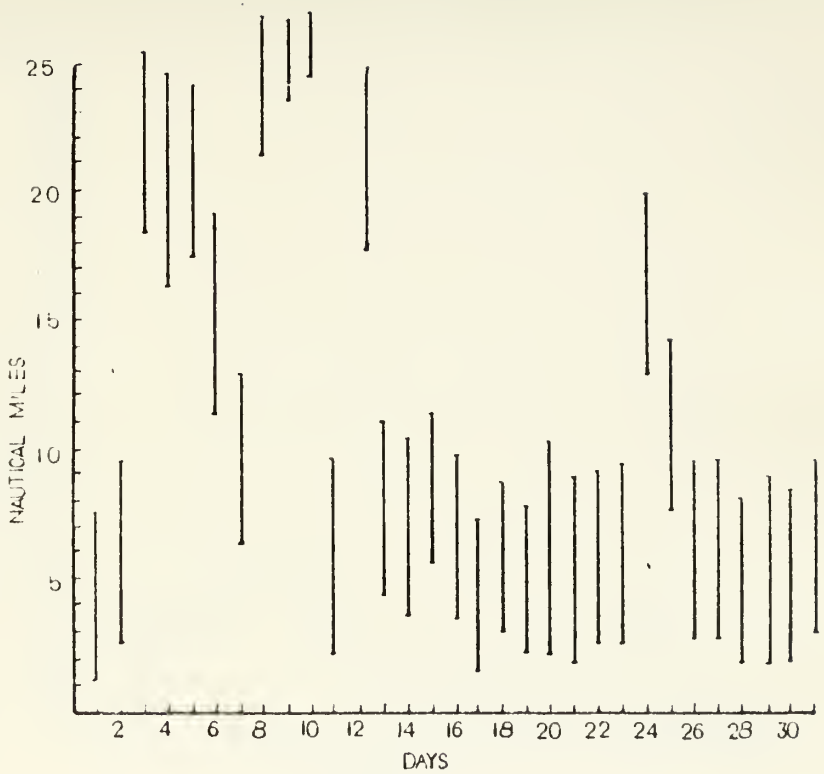


Figure 9

Measurement uncertainty for the EOTS-FACT analysis for FOM of 80±1 dB, 300 Hz and receiver depth of 200 feet.

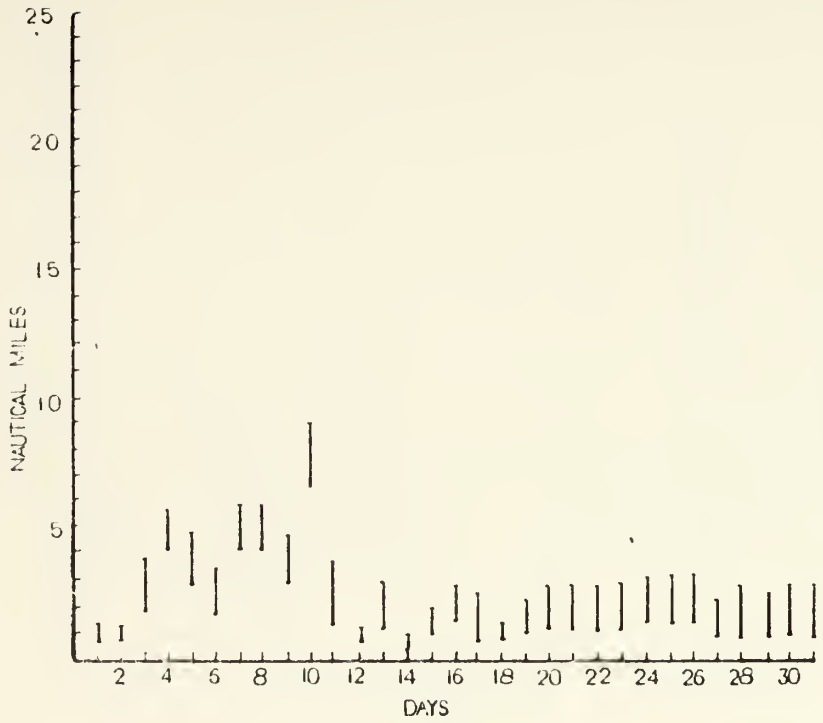


Figure 10

Measurement uncertainty for the EOTS-FACT analysis for FOM of 75±1 dB, 50Hz and receiver depth of 200 feet.

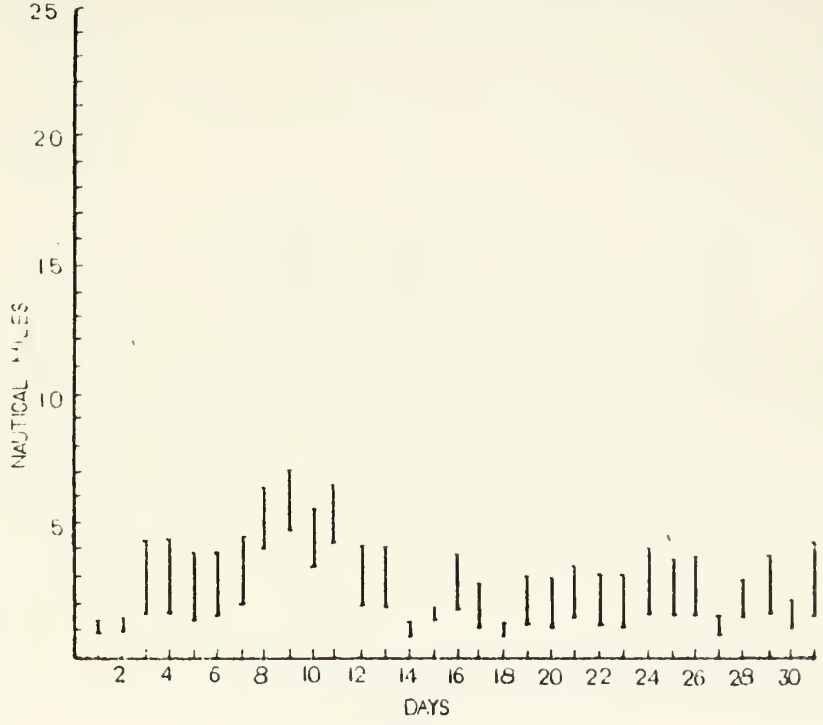


Figure 11

Measurement uncertainty for the EOTS-FACT analysis for FOM of 75±1 dB, 300Hz and receiver depth of 200 feet.

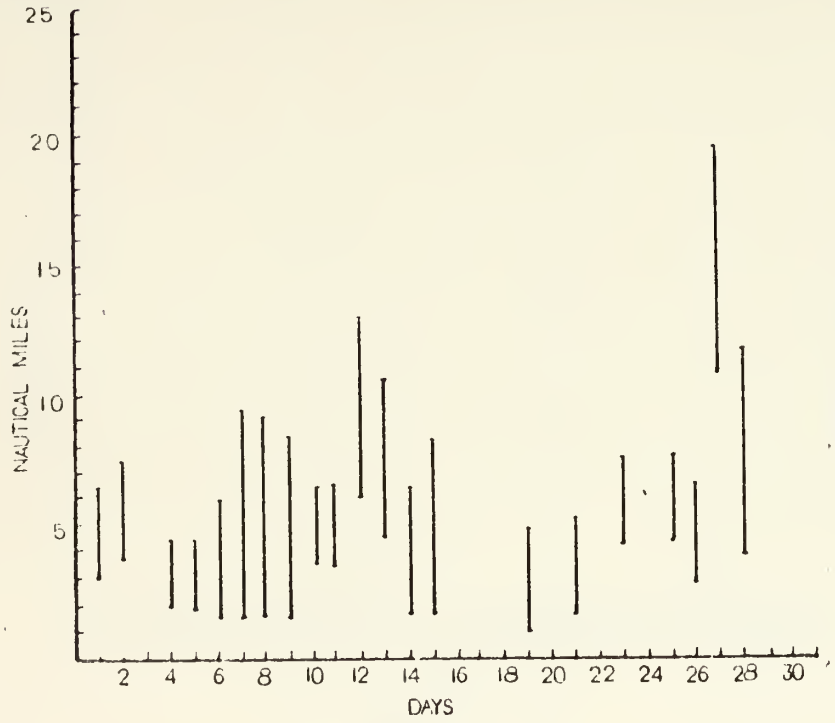


Figure 12

Measurement uncertainty for the BT-FACT analysis for FOM of 80±1 dB, 50Hz and receiver depth of 200 feet.

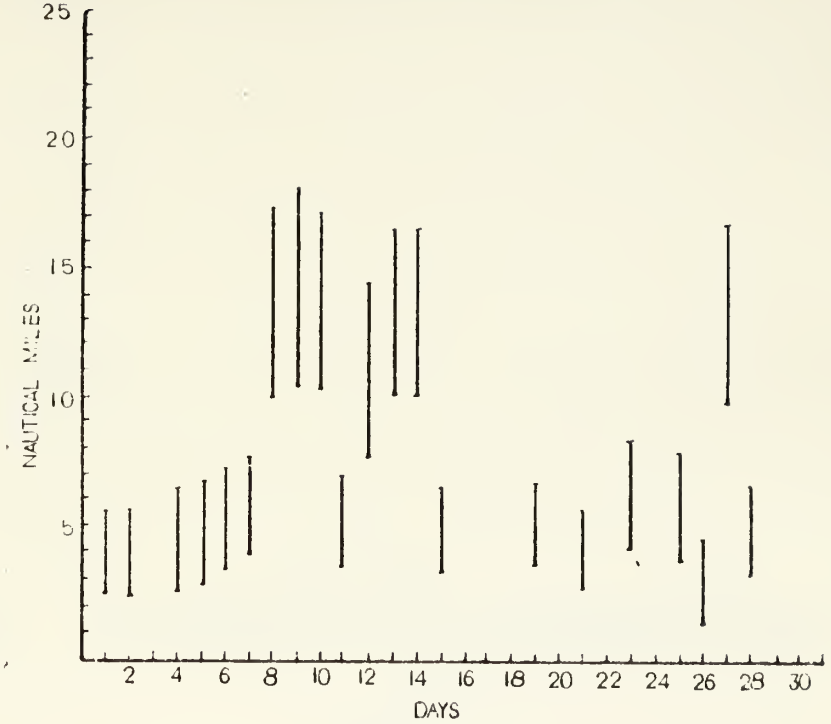


Figure 13

Measurement uncertainty for the BT-FACT analysis for FOM of 80±1 dB, 300 Hz, and receiver depth of 200 feet.

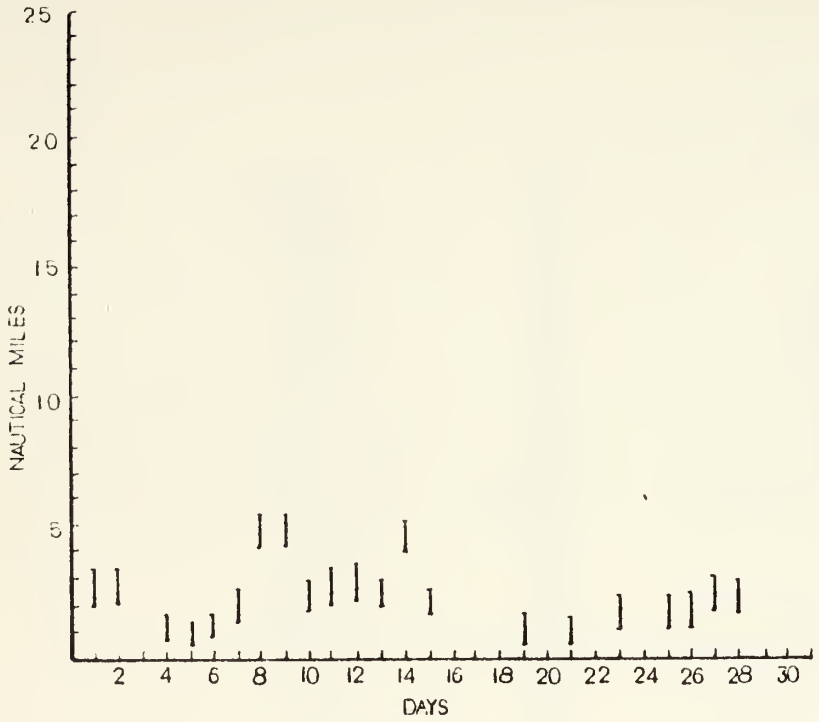


Figure 14

Measurement uncertainty for the BT-FACT analysis for FOM of 75±1 dB, 50 Hz and receiver depth of 200 feet.

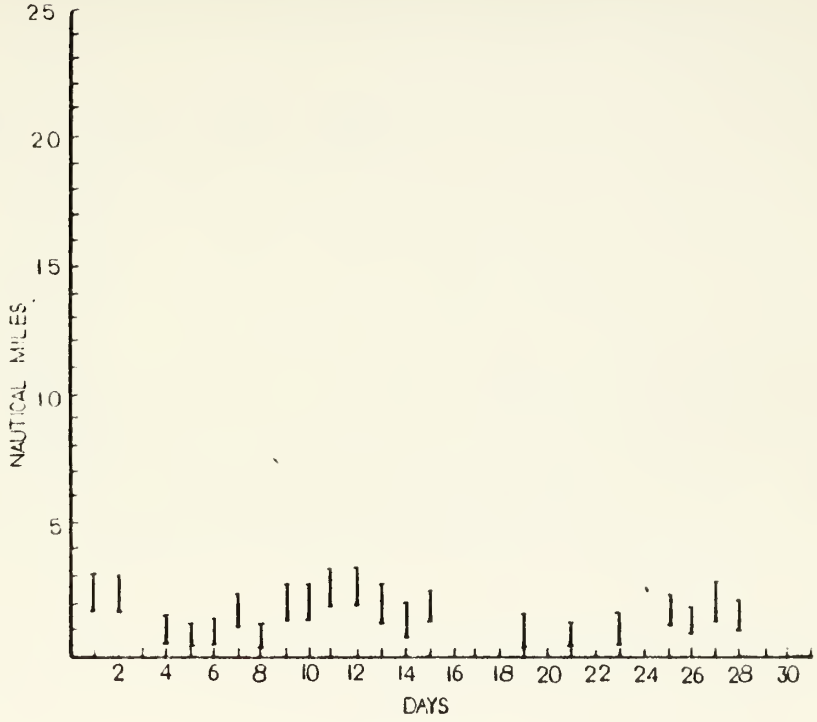


Figure 15

Measurement uncertainty for the BT-FACT analysis for FOM of 75±1 dB, 300 Hz and receiver depth of 200 feet.

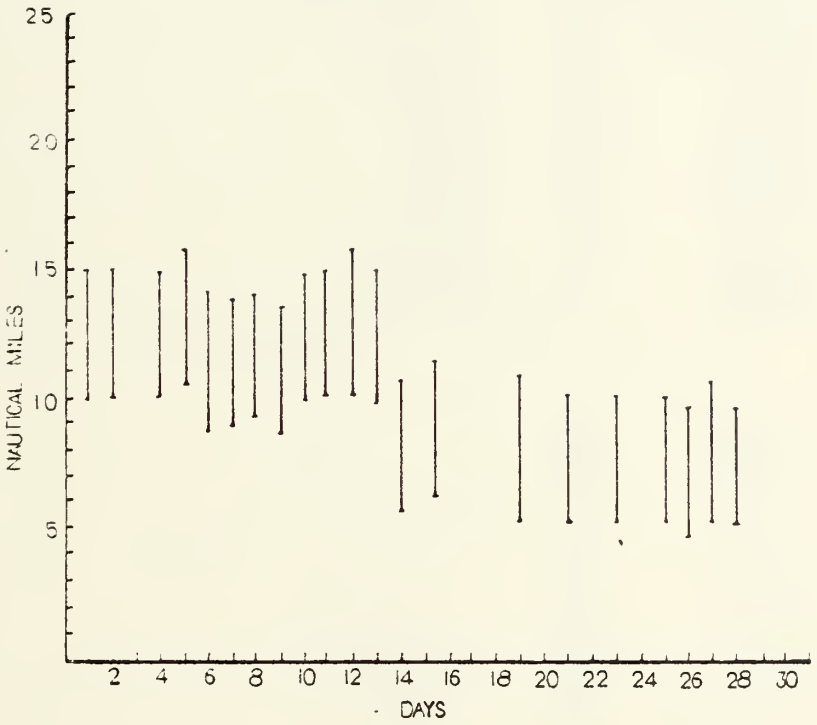


Figure 16

Measurement uncertainty for the BT-FACT analysis for FOM of 80±1 dB, 300 Hz and receiver depth of 200 feet.

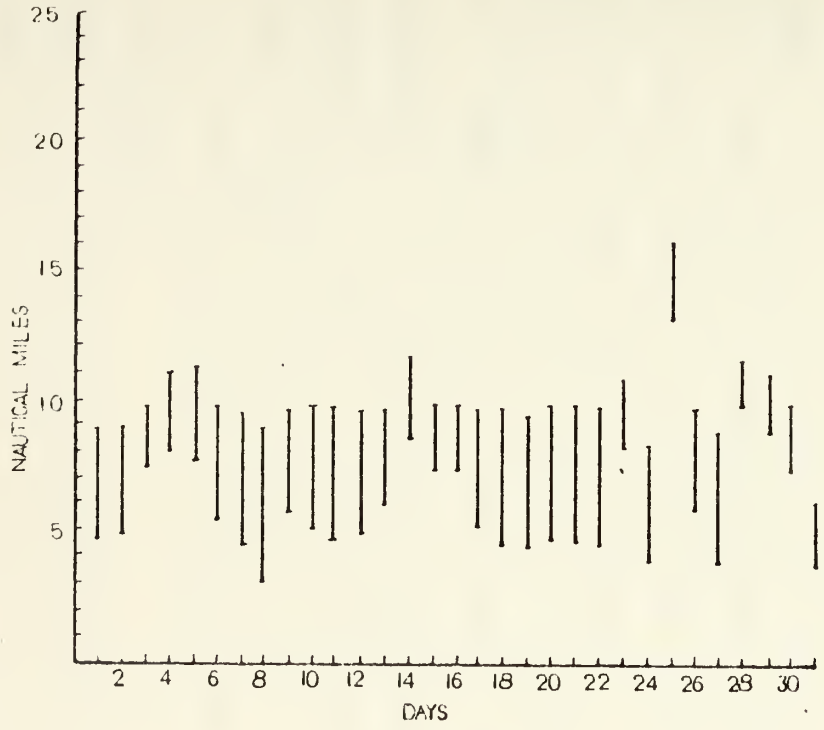


Figure 17

Measurement uncertainty for the EOTS-FACT analysis FOM of 80±1 dB, 300 Hz and receiver depth of 200 feet.

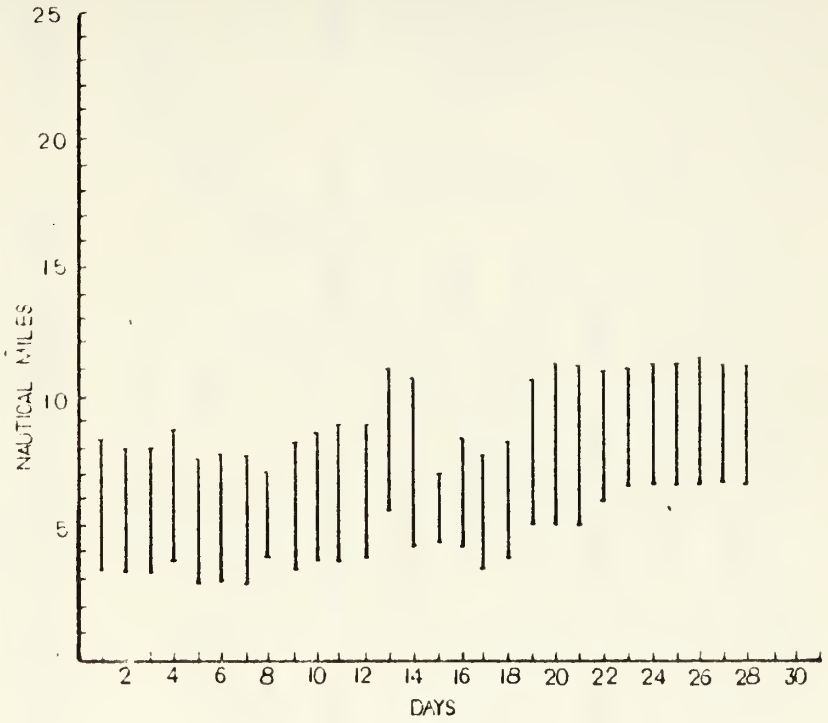


Figure 18

Measurement uncertainty for the ODT-FACT analysis for FOM of 80±1 dB, 300 Hz and receiver depth of 200 feet.

sensitivity to FOM in that a larger uncertainty is observed near the FOM of 80 dB than at the FOM of 70 dB. Also, the range of uncertainty is fairly constant for a given figure of merit. At the 74-76 dB FOM, the range of uncertainty appears to lie between 2 and 3 nautical miles, while at the 79-81 dB FOM, the uncertainty range is between 7 and 9 nautical miles. There doesn't appear to be any dependence on frequency as far as the range of uncertainty is concerned. However figures 16 through 18 show that when the receiver depth changes from 200 feet to 700 feet, the range of uncertainty for the 79-81 dB FOM decreased to 5-6 nautical miles.

D. DATA SOURCE: OCEAN WEATHER STATION (OWS) PAPA:

The point of analysis of the three model systems was chosen to be OWS Papa for several reasons. First, there are regular BT reports (daily) from OWS Papa providing an acceptable reference for an actual time series analysis. Secondly, the ODT model has been shown to accurately predict the thermal structure at OWS Papa [Elsberry and Garwood, 1980]. Thirdly, the oceanography of OWS Papa and the surrounding region is well documented. An analysis of the meteorogolical conditions at OWS Papa during the month of May was made to gain insight into the effects of atmospheric forcing on both thermal and acoustic parameters.

OWS Papa is located in the Northeast Pacific Ocean, south of the Alaskan Gyre in the vicinity of the Eastern Sub-artic Pacific Water Mass (Fig. 19). The station has been manned by

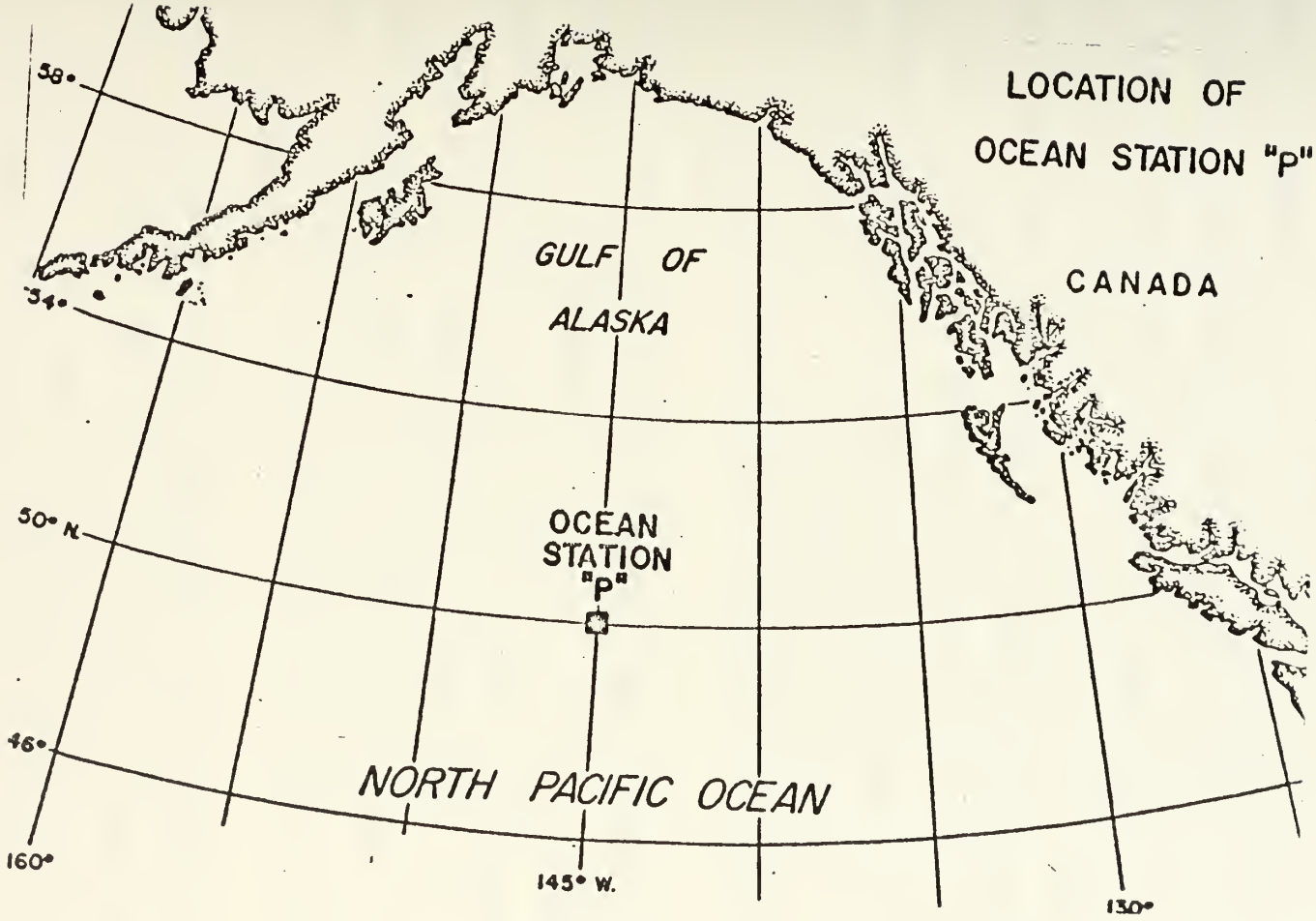


Figure 19

Location of Ocean Station Papa

From S. Tabata, "The effect of heat exchange and winds on the summer temperature structure of the surface water at station "p" in the Eastern Subarctic Pacific Ocean." Journal of Fisheries Resources Board, Canada, February 15, 1962.

Canadian weatherships since December 1950. Originally, the station operated as a meteorological station for surface and upper air observations and to serve as an air-sea rescue station. Beginning in July 1952, the Pacific Oceanographic group of the Fisheries Research Board of Canada in cooperation with the Canadian Coast Guard Service made regular bathymetric observations at the station. All physical data collected at OWS Papa have been archived by the Canadian Oceanographic Data Center in Ottawa, Ontario, Canada and include depth versus temperature summaries as well as salinity, oxygen, and sound velocity calculations. Unfortunately, commencing in June 1981, the site will no longer be continually occupied due to lack of funding.

The ODT model was evaluated at OWS Papa during the Fall of 1976 [Elsberry, Gallacher, Garwood, 1979]. The model appeared to represent correctly the vertical mixing processes on the monthly time scales tested. For the Fall 1976 experiment, the ODT model was initialized with actual BT soundings, and the model was verified at OWS Papa on monthly time periods only.

For the purposes of this analysis, the ODT model was used for daily predictions and only required information (marine winds, total heat flux, solar radiation) obtainable from FNOC to drive the model. Initialization could have been accomplished by an actual BT or a thermal profile from the EOTS analysis.

As stated earlier, an isothermal profile (0-200 meters) was used to initiate the ODT model in order that it not be biased to EOTS or the actual BT results. Even more accurate results could have been obtained if an actual BT had been used to initiate the model. The ODT model deals only with near surface vertical mixing processes and is insensitive to the thermal structure below 200 meters.

In order to understand coupled model systems, a brief explanation of each individual model follows. Terms and definitions of parameters are contained in the glossary.

II. MODEL THEORY

A. FACT MODEL

The FACT model is the Navy Standard Model established in April 1973 [Spofford, 1974] for passive acoustic products. It presently is operational at the Fleet Numerical Oceanography Center. The model is a ray-acoustics model designed for the computation of transmission loss as a function of range and frequency at fixed source and receiver depths. It is characterized by (1) a single sound velocity profile (SVP) representative of an entire region (2) bottom depth constant (flat bottom approximation) (3) bottom composition and roughness constant throughout the area.

Transmission loss is determined by the type and number of arrival paths carrying sound to the receiver. The intensity level at the receiver is the sound arriving from (1) a surface duct (2) a totally refracted path as found in a convergence zone (3) a totally reflected path as in bottom bounce or (4) a deep refracted, surface reflected path. The computation logic of the model determines that ray arrival paths are either surface ducted, or they are not surface ducted.

When there is no surface duct propagation, each ray in a given bundle is treated as a member of a family of rays. Each family then represents total energy arriving at the

receiver by a distinct path. As the rays within a family may cross several times as the sound propagates from source to receiver, focussing and defocussing of the rays along the path of propagation occurs. At the crossing points, the caustics, second order non-linear functions are used to compute the acoustic intensity (TL), as the intensity approaches infinity if first order functions are used.

For surface ducted cases, either source or receiver is located in the surface duct. The intensity in the surface duct is found from equations based on conservation of energy that are modified by additional losses (proportional to range) resulting from duct leakage or rough-surface scattering of energy from the duct. If both the source and receiver are in the duct, the basic intensity calculation is independent of the source or receiver depth. For cross duct cases (only source or receiver in the duct) the intensity calculation is reduced by 10dB.

Once the appropriate ray families arriving at the receiver have been specified, each ray family undergoes a second order curve fitting routine designed to eliminate false caustics. Only the surface ducted rays do not undergo this smoothing routine. The intensity is then computed at regular range increments (½ nautical mile) from the source to 125 nautical miles from the source. The intensity at the receiver at any distance from the source is specified in terms of depth of the source, angle that the ray emanates from the source,

angle the ray arrives at the receiver, distance from source to receiver, and the slope of the source angle versus range curve evaluated at the depth of the receiver [Spofford, 1974]. The intensity at the receiver is reduced further by the inclusion of frequency dependent loss terms associated with absorption and bottom reflection.

The input parameters to the FACT model are (1) sound velocity profile (2) frequency (3) source-receiver depth, and (4) bottom-type. For ducted transmission, wave height and windspeed are also parameters.

The output from the FACT model can be displayed in many forms, each of which is suited to the operational user, [FNOC, 1979]. The information contained in the output products is identical, only the format varies. As stated earlier, DBPLOT was the output format utilized to evaluate the model systems in this analysis.

1. Limitations

The FACT model has known deficiencies [Spofford, 1974]. For this analysis, low frequency effects, half channel effects and surface duct effects bear directly on the results. The EOTS-FACT experiment was characterized by moderate surface ducting, some subsurface ducting and some half channel cases. The ODT-FACT experiment exhibited basically half channel effects with very slight cases of surface and subsurface ducting. The reference BT-FACT system displayed marked

surface and subsurface ducting with some cases involving convergence zone propagation. For the entire study, the low frequency (25 Hz) was realistically below the cutoff frequency as the duct thickness required would be in excess of 360 meters for the frequency to be ducted. The following is a brief description of these effects.

a. Low Frequency

At low frequencies nearing cutoff (geometries with dimensions of several wavelengths), basic model assumptions may be incorrect. In the FACT model, the transmission loss is computed by summing on an incoherent or RMS basis the intensities of families of rays at a point. As frequencies decrease to near cutoff, large scale cancellations of caustics occur resulting in significant degradation from the RMS intensity calculations. The extension of ray theory to situations which should be treated by wave (normal mode) techniques is speculative at best. [Spofford, 1974]

b. Half Channel

For half channel cases in which the sound speed increases monotonically from the surface to the bottom, considerable computer time is consumed in obtaining a transmission loss curve for the refracted surface reflected (RSR) paths which is quite smooth due to the overlap of arrival orders. In these cases, the water is nearly isothermal and the key input parameters are the source and receiver depths,

water depth and frequency. This routine is valid only for precise ASRAP geometries and frequencies which include source and receiver depths of 200 feet and 300 feet and frequencies of 50 Hz and 300 Hz [Spofford, 1974]. When surface image interference is possible, the FACT model description shows that as frequency increases to 200 Hz, transmission loss decreases. As the frequency then increases to beyond 300 Hz, transmission loss increases. [Spofford, 1974]

c. Surface Duct Propagation

When either the source or receiver is located in the surface duct, the surface duct module of the FACT model is used for intensity level calculations. For most of the surface ducted cases in the analysis, there is a decrease in transmission loss (increase in MDR) as frequency increases. In all surface ducted cases, the 25 Hz frequency passes through the duct. The 50 Hz frequency is ducted for a few cases while both the 150 Hz and 300 Hz frequencies are ducted in all three analyses. For ducted propagation, a frequency of 50 Hz would require a duct thickness of approximately 230 meters while a frequency of 300 Hz would require a duct thickness of only 70 meters.

B. ONE DIMENSIONAL THERMODYNAMIC (ODT) MODEL

The ODT model is a one dimensional model [Garwood, 1979] based on the physics of mixed layer dynamics. The model employs the turbulent kinetic energy budget to predict the

changes in the vertical temperature profile due to turbulent mixing. Heat flux, solar radiation, and marine winds, three atmospheric fields catalogued by FNOC yield the boundary conditions that drive the model. There are two basic modes of action in the model: (1) an entrainment mode or deepening of the thermal layer, and (2) a retreat mode or shallowing of the thermal layer. In the entrainment mode, the model generates an entrainment velocity taking into account the heat equation at the base of the mixed layer. Having been initialized by a given thermal profile, the model computed vertical heat flux is then imposed upon this temperature profile within the constraints of the heat budget.

In the retreat mode, both heat and potential energy are conserved. Shallowing of the mixed layer can only occur if there is a net heat added due to solar radiation less back radiation and turbulent fluxes at the surface. Vertical mixing processes redistribute the heat in the water column. The nonlinearity of this vertical mixing process in the ocean surface boundary layer requires that the atmospheric forcing field be input hourly, even though one is trying to explain anomalies with time scales varying from days to weeks or longer.

Since it is impossible to monitor heat and momentum fluxes hourly, surface heat budget calculations from the FNOC atmospheric prediction model are used. The ODT model in turn predicts the evolution of the oceanic thermal structure

profile at a given location. The procedure for converting FNOC fluxes prescribed at 6 to 12 hour intervals is given by Gallacher (1979). This capability to reconstruct hourly values of the solar flux from instantaneous values is extremely important for properly computing the vertical mixing process.

The ODT model considers only vertical fluxes of heat. Consequently, a necessary condition for accurate model predictions is that the change in heat content during the period must be nearly equal to the time integral of the net surface heat flux.

In summary, the inputs to the ODT model are total heat flux, marine winds, and solar radiation and the output is a thermal profile representing the mixing dynamics in the upper oceanic regions for a specific point. This model does not account for changes below 200 meters and makes no attempt at predicting changes in the below-layer gradient structure.

C. EOTS MODEL

The Expanded Ocean Thermal Structure (EOTS) model currently used by FNOC is a computer oriented model application of the general purpose Fields by Information Blending (FIB) methodology [Holl, 1979]. It is an advanced, comprehensive and flexible system using a four dimensional numerical analysis of thermal structure from the ocean surface to 400m. From

400 meters to 1200 meters there is a piecewise linear blending zone to the EOTS climatology and below 1200 meters, the thermal profile consists of only climatology.

By the use of surface, airborne expendable BT's, and satellite data, an analysis can be performed for any region in the Northern Hemisphere for any grid resolution in space and time. Significant variabilities in the vertical temperature profile are represented by a set of twenty-six thermal structure parameters consisting of absolute temperature values, and gradients at selected depth intervals. Sea surface temperature changes dominate the near surface blending region. A special provision is made for a finer resolution of the thermal structure in the vicinity of the primary layer depth and for the restriction of flow of information across land barriers. The EOTS system is presently used by FNOC for real-time synoptic analysis and production of historical climatology. This model produces oceanic thermal structure fields for input to acoustic performance models. The EOTS data base is currently restricted to the Northern Hemisphere and a 63x63 grid (approximately 4000 data points) is superimposed over the area. The EOTS grid structure can also be applied as a fine mesh grid for local areas such as the Gulf Stream, where higher data availability will support a finer resolution. Actual BT reports are extrapolated to the nearest grid point. Grid points are weighted by the

number of BT's and how recently information has been accrued. Presently, a BT is kept in the system impacting the thermal structure for five days. Then it is discarded and no longer influences the model generated thermal profiles. If there is no current data (BT) for a grid point, then that grid point will automatically revert to climatology [Holl, 1979].

Basically, the blending technique is as follows.

(1) A first guess or parameter initialization field (PIF) is made.

(2) In assembly, new information undergoes a gross error check and is then readied for blending.

(3) Horizontal blending occurs and BT readings are extrapolated to their nearest grid points. Then reliability and weighting are assigned to grid points based on the number and currency of BT's.

(4) Vertical blending occurs at each grid point. The influence is propagated to the grid point above and below the grid point being analyzed. The vertical blending is done to 400 meters. From 400 meters to 1200 meters the EOTS data is merged with climatology and below 1200 meters, the thermal profile is a function of the monthly climatology only.

The inputs to EOTS consist of numerous BT observations. The intermediate products are the field created by the FIB methodology. Upon request for a specific latitude/longitude, the output information is a thermal/sound speed profile for that latitude/longitude as extrapolated from the FIB methodology.

III. MODEL SYSTEMS AND EXPERIMENTAL RESULTS

The model systems examined were processed independently of each other. The BT-FACT product is the reference for the three experiments. The following data is a result of acoustic analysis of the output product DBPLOT.

For all three data sets, the propagation loss curve was entered using three figures-of-merit: 70 dB, 75 dB and 80 dB. These figure-of-merit (FOM) values were then used with an overlay on the propagation loss curves to obtain the parameter, median detection range (MDR).

The acoustic results were based on a scenario of a source at a constant depth of 300 feet, and receivers placed at 200 feet, 700 feet and near the bottom (12,770 feet). Frequencies analyzed were 25 Hz, 50 Hz, 150 Hz and 300 Hz. The Figure of Merit was used as an entering argument in order to account for source level and ambient noise. Operationally, a fleet user enters the propagation loss curve with a given figure of merit (FOM) in order to extract the median detection range (MDR). A number of values for figure of merit were used in order to further enhance the value of the data and lend insight for a trend analysis. After the acoustic data was gathered, statistics were computed to use as a tool of evaluation. The significance level of the statistics is questionable (in absolute terms) due to the relatively small amount of data processed.

A. EOTS-FACT ACOUSTIC ANALYSIS

The following acoustic observations are noted for the EOTS-FACT output for May 1-31, 1980.

At 70 dB FOM (Fig. 20), the absolute value of median detection range as a measure of effectiveness is relatively unchanged with frequency at a constant receiver depth. Realistically, the accuracy limits of the system are being tested as the FACT model is accurate in this analysis to ½ nautical mile. Even at the increased receiver depth of 700 feet, the virtual insensitivity of the system with regard to frequency is shown (Fig. 21).

As the figure of merit is increased to 75 dB at a receiver depth of 200 feet, a noticeable increase in the variability of MDR is seen on a daily basis (Fig. 22). The effects of frequency become more noticeable as the system displays a higher sensitivity as FOM increases to 75 dB (Fig. 22). The frequency variation observed in figure 22 is not consistent throughout the time series. This could be the result of "noise in the system" or uncertainty errors in the accuracy of the data collection. At the 700 foot receiver depth (Fig. 23), there is less day-to-day frequency variability than at the 200 foot receiver. The overall range-of-values of MDR at the 700 foot receiver, on a daily basis, is not as dramatic as at the 200 foot receiver.

At 80 dB FOM and a receiver depth of 200 feet (Fig. 24) the model system develops an almost hypersensitivity to

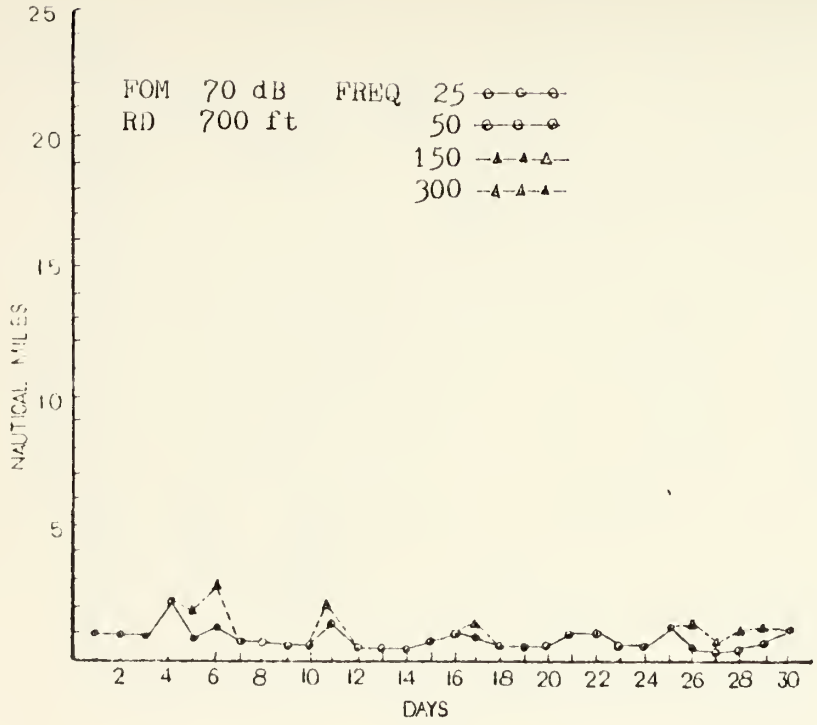


Figure 20

Median detection range (MDR) versus time for the EOTS-FACT analysis: FOM of 70 dB, receiver depth of 200 feet, frequency range of 25 Hz, 50 Hz, 150 Hz, 300 Hz.

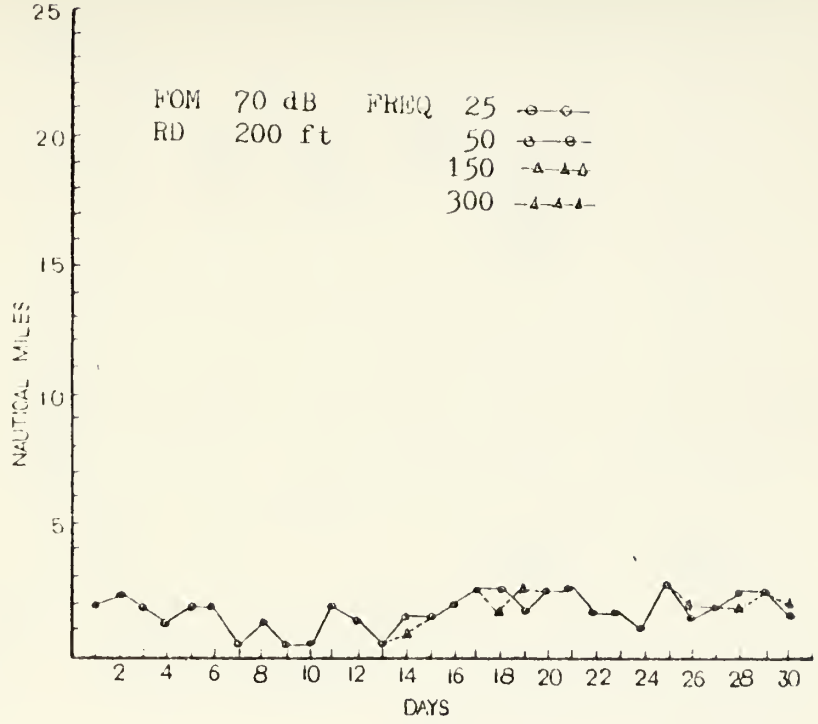


Figure 21

Median detection range (MDR) versus time for the EOTS-FACT analysis: FOM of 70 dB, receiver depth of 700 feet, frequency range of 25 Hz, 50 Hz, 150 Hz, 300 Hz.

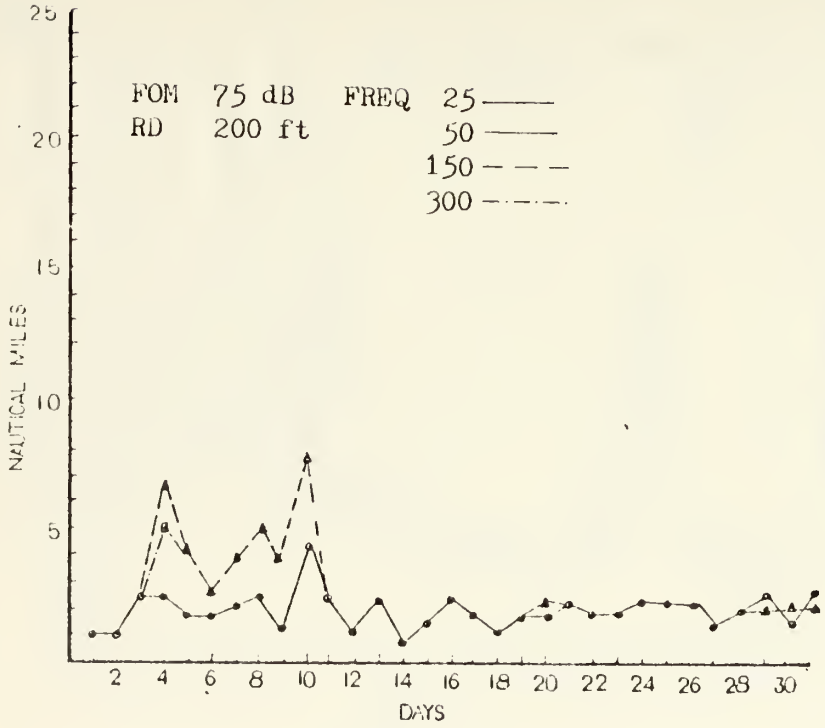


Figure 22

Median detection range (MDR) versus time for the EOTS-FACT analysis: FOM of 75 dB, receiver depth of 200 feet, frequency range of 25 Hz, 50 Hz, 150 Hz, 300 Hz.

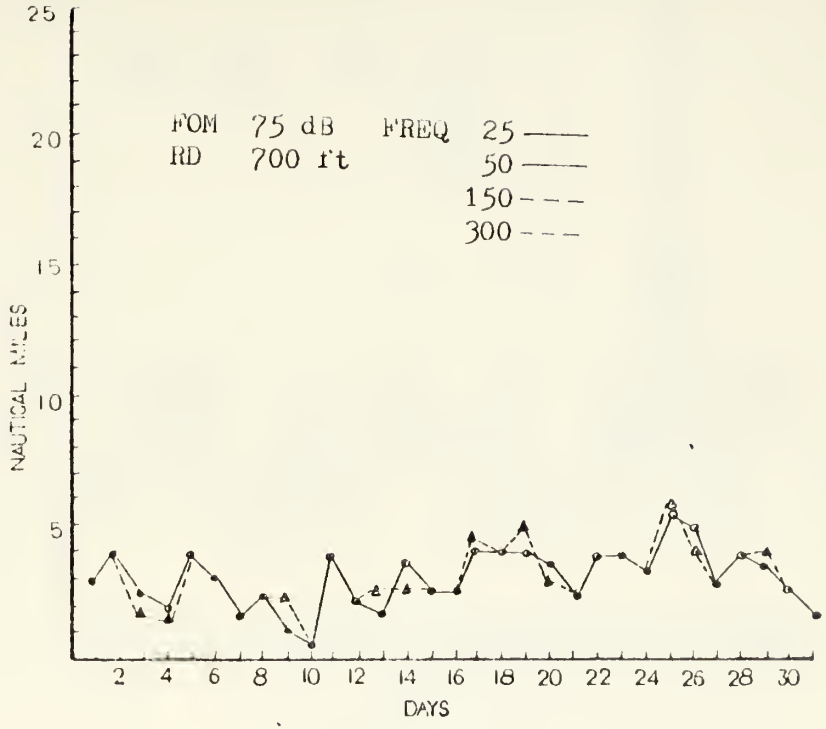


Figure 23

Median detection range (MDR) versus time for the EOTS-FACT analysis: FOM of 75 dB, receiver depth of 700 feet, frequency range of 25 Hz, 50 Hz, 150 Hz, 300 Hz.

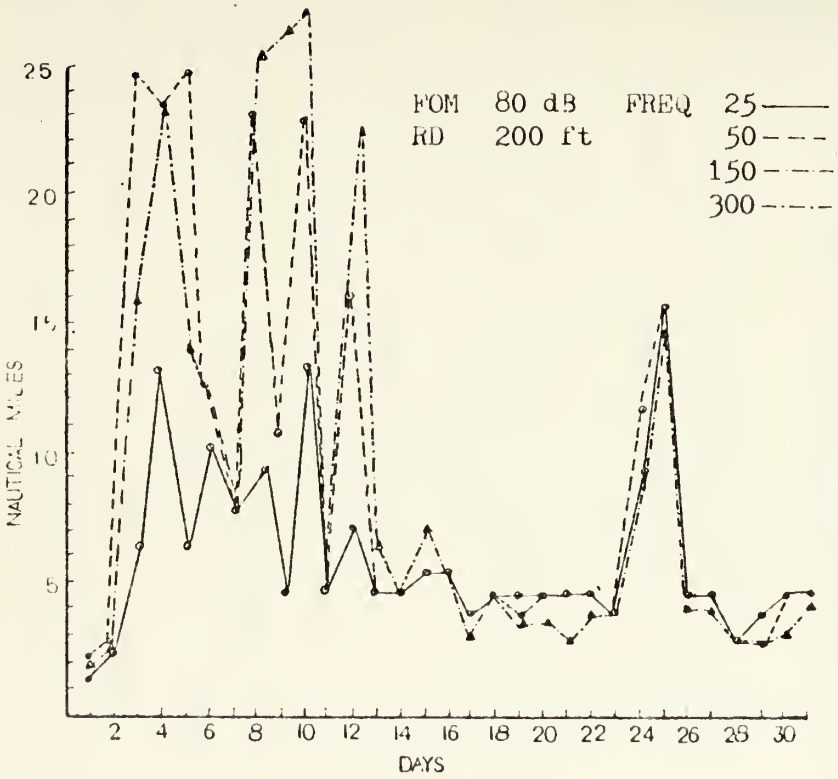


Figure 24

Median detection range (MDR) versus time for the EOTS-FACT analysis: FOM of 80 dB, receiver depth of 200 feet, frequency range of 25 Hz, 50 Hz, 150 Hz, 300 Hz.

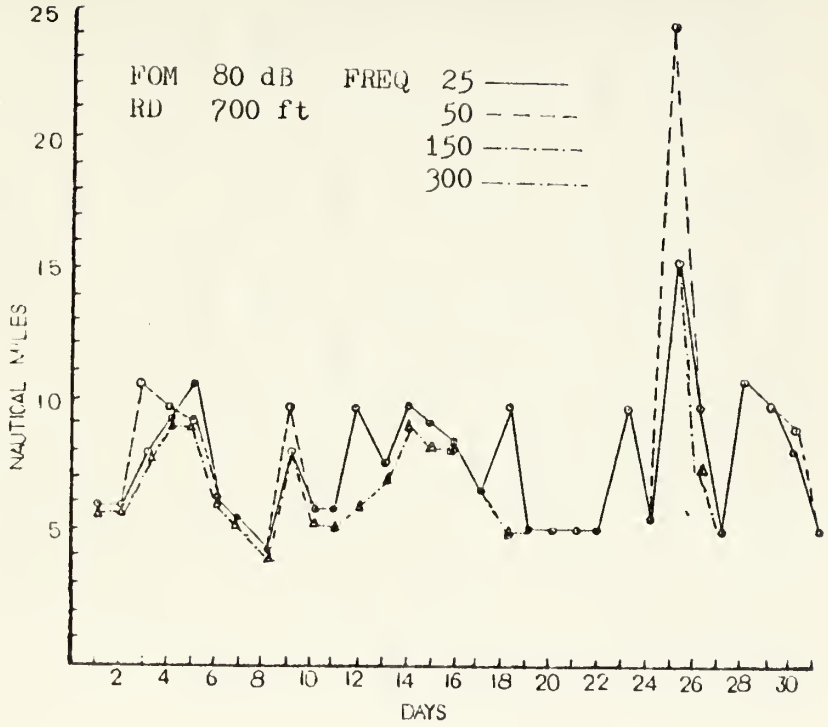


Figure 25

Median detection range (MDR) versus time for the EOTS-FACT analysis: FOM of 80 dB, receiver depth of 700 feet, frequency range of 25 Hz, 50 Hz, 150 Hz, 300 Hz.

frequency as surface ducting and surface image interference are accentuated. The time series representation of MDR showed tremendous daily variance. At the 700 foot receiver depth, MDR appears less a function of frequency (Fig. 25). At the near bottom receiver, MDR is constant at 11 nautical miles and remains unchanged for the entire time series analysis and appears virtually independent of frequency.

Regardless whether or not the 200 foot receiver or the 700 foot receiver was used (Figs. 26-33), the mean MDR for the time series was relatively constant (Table 1) for a fixed FOM. However there may have been more day-to-day variability at the 200 foot receiver as evidenced by figures 26-33 and supported by the respective standard deviations of the mean MDR (Table 1).

Subjective acoustic analysis reveals a great degree of acoustic variability present at 80 dB FOM when the data is observed as a time series (Fig. 24). As FOM increases, the magnitude of the MDR variance increases significantly (Figs. 34-39). Most notably, as the FOM is increased from 75 dB to 80 dB, there is a marked increase in the day-to-day acoustic variability. Varying the receiver depth from 200 feet to 700 feet had a slight affect on the mean MDR but moreover showed that the day-to-day variability of MDR was reduced somewhat. The variance of the MDR as frequency was changed was dependent on the FOM. Frequency effects were not significant

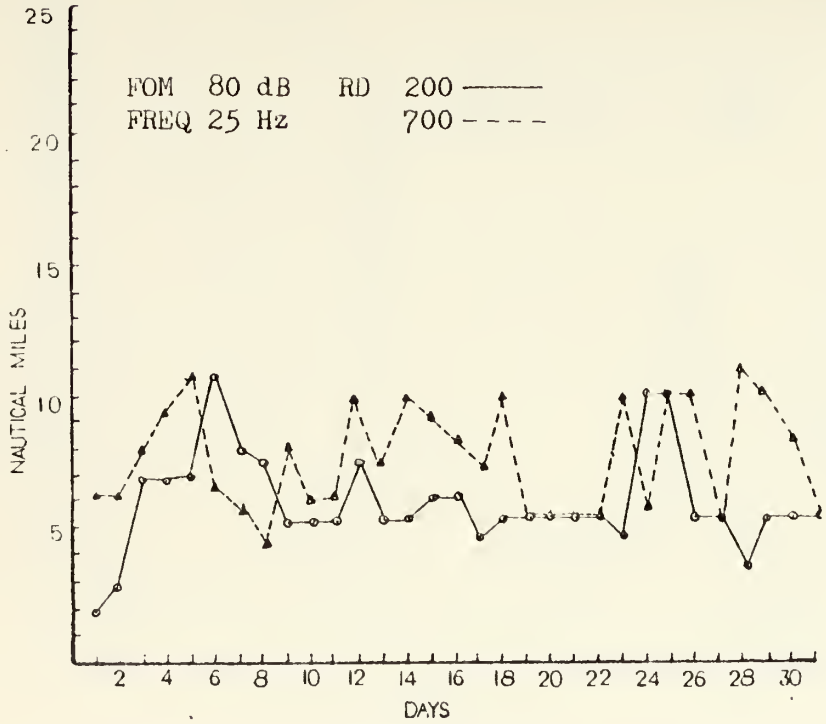


Figure 26

Median detection range (MDR) versus time for the EOTS-FACT analysis: Comparison of 200 foot receiver to 700 foot receiver at 25 Hz and a FOM of 80 dB.

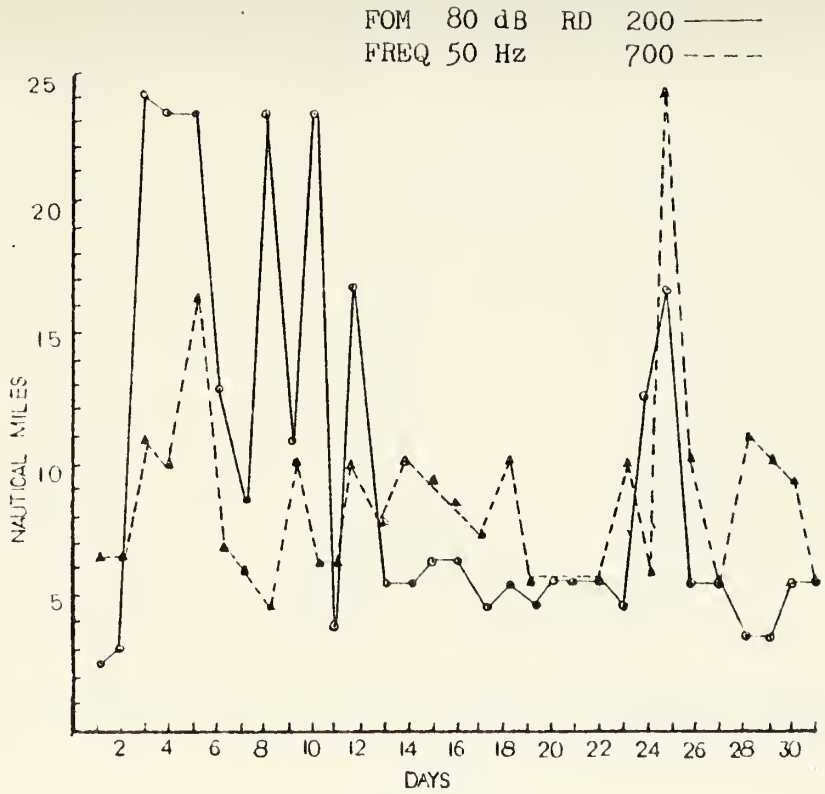


Figure 27

Median detection range (MDR) versus time for the EOTS-FACT analysis: Comparison of 200 foot receiver to 700 foot receiver at 50 Hz and a FOM of 80 dB.

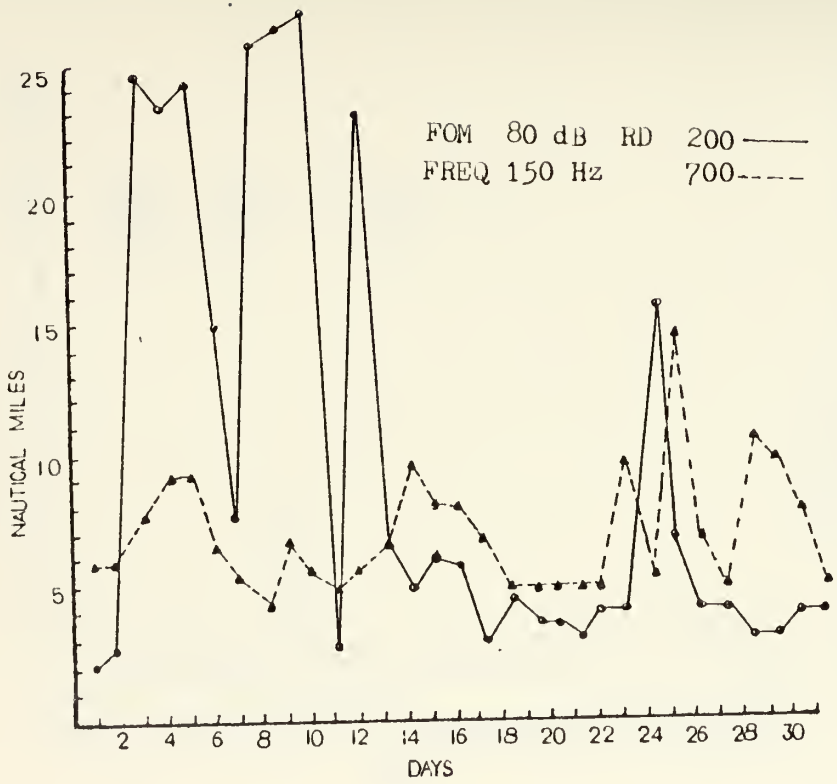


Figure 28

Median detection range (MDR) versus time for the EOTS-FACT analysis: Comparison of 200 foot receiver to 700 foot receiver at 150 Hz and a FOM of 80 dB.

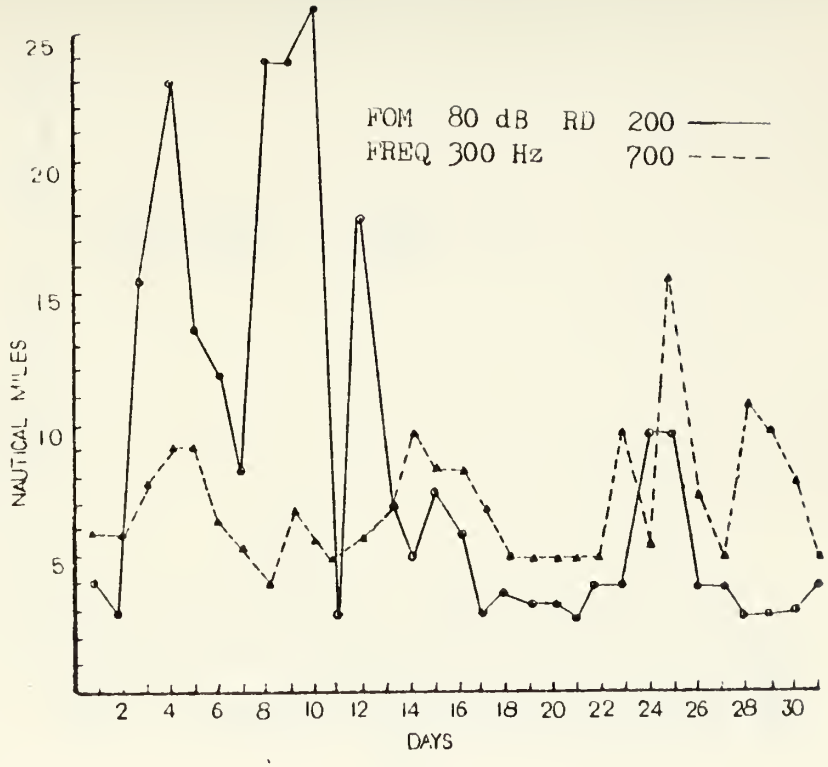


Figure 29

Median detection range (MDR) versus time for the EOTS-FACT analysis: Comparison of 200 foot receiver to 700 foot receiver at 300 Hz and a FOM 0f 80 dB.

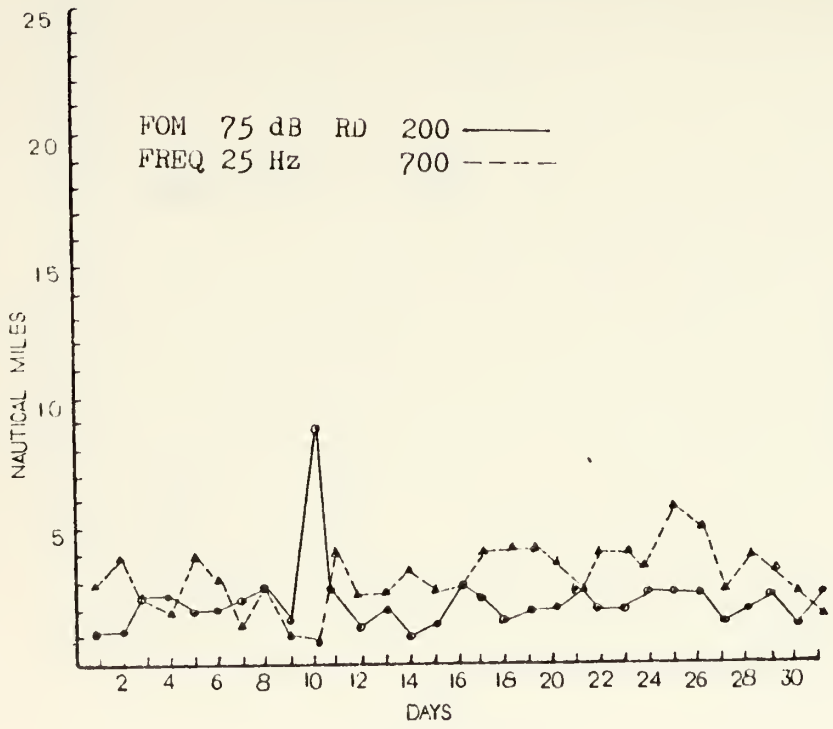


Figure 30

Median detection range (MDR) versus time for the EOTS-FACT analysis: Comparison of 200 foot receiver to 700 foot receiver at 25 Hz and a FOM of 75 dB.

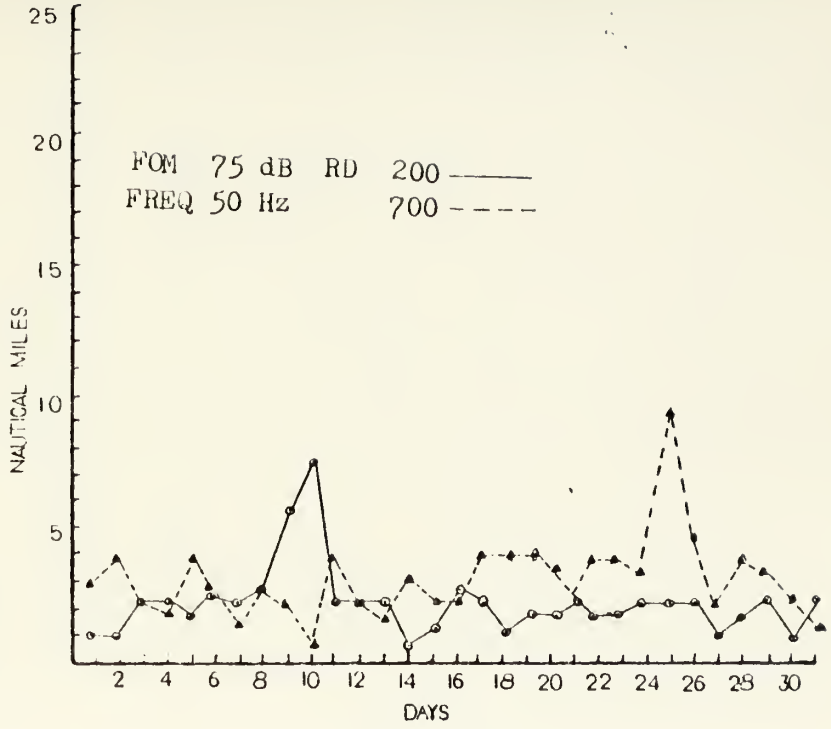


Figure 31

Median detection range (MDR) versus time for the EOTS-FACT analysis: Comparison of 200 foot receiver to 700 foot receiver at 50 Hz and a FOM of 75 dB.

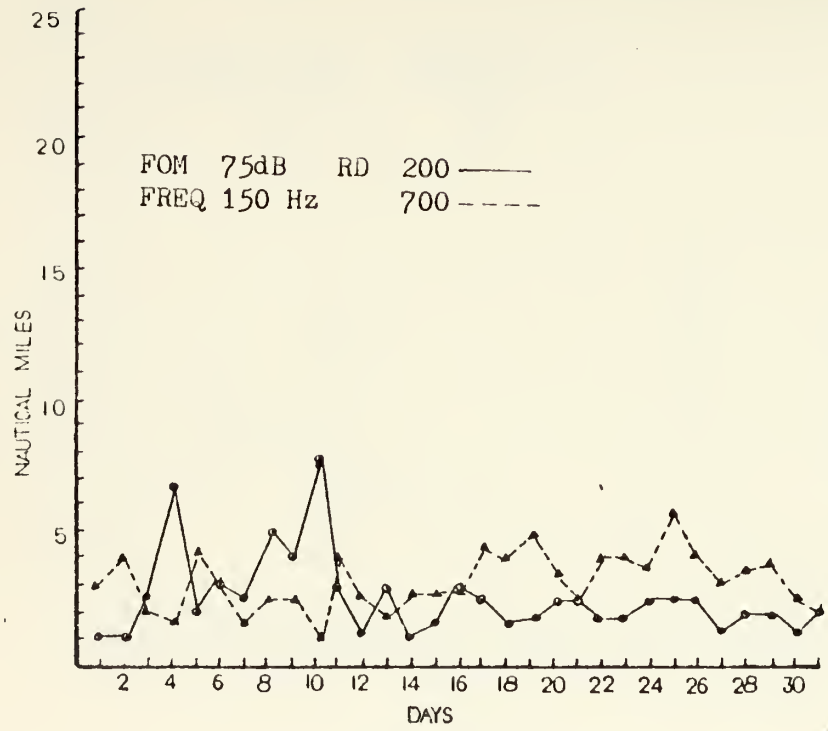


Figure 32

Median detection range (MDR) versus time for the EOTS-FACT analysis: Comparison of 200 foot receiver to 700 foot receiver at 150 Hz and a FOM of 75 dB.

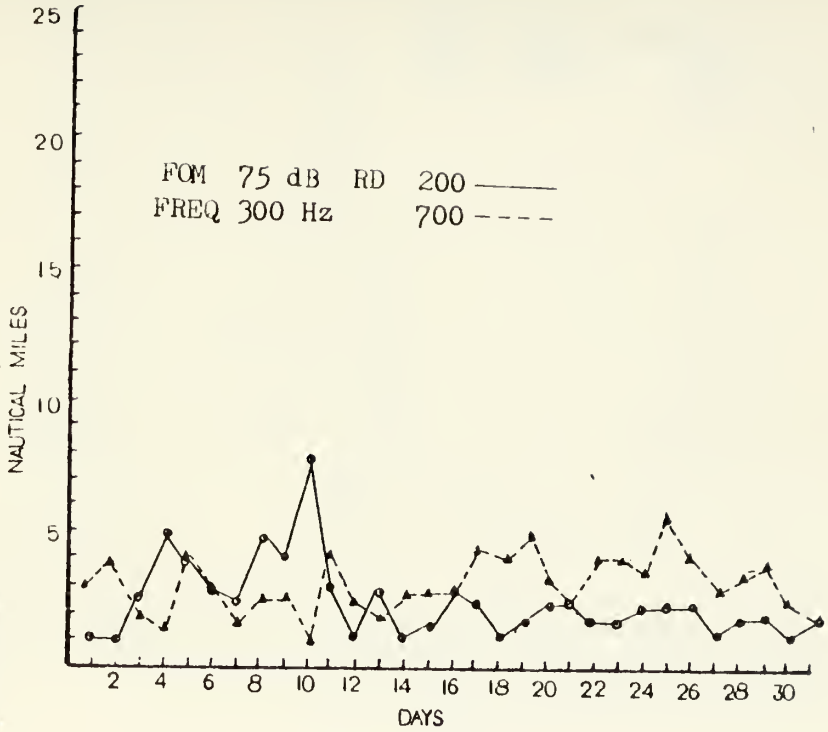


Figure 33

Median detection range (MDR) versus time for the EOTS-FACT analysis: Comparison of 200 foot receiver to 700 foot receiver at 300 Hz and a FOM of 75 dB.

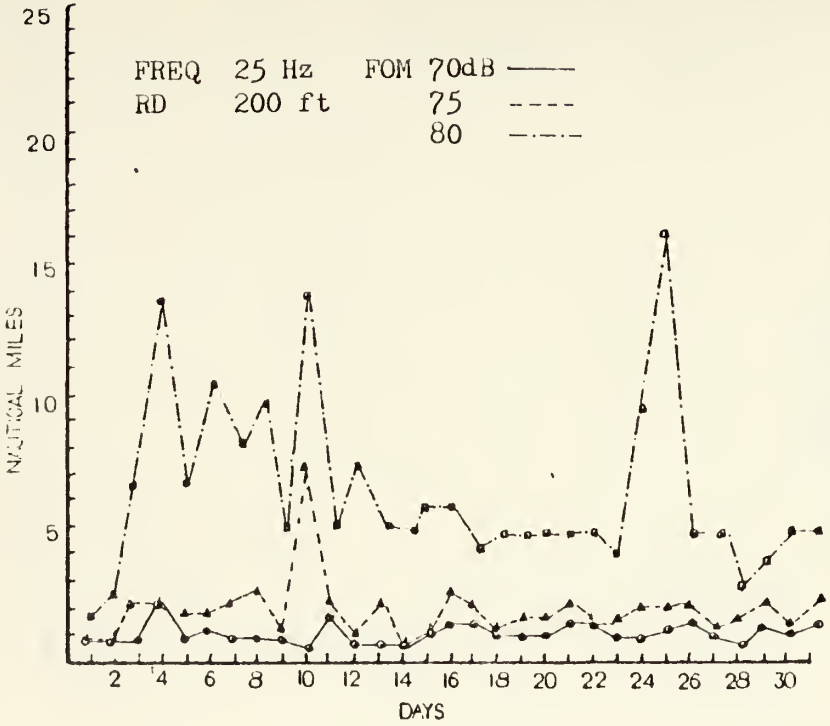


Figure 34

Median detection range (MDR) versus time for EOTS-FACT analysis: Comparison of FOM's of 70 dB, 75 dB and 80 dB, at 25 Hz and receiver at 200 feet.

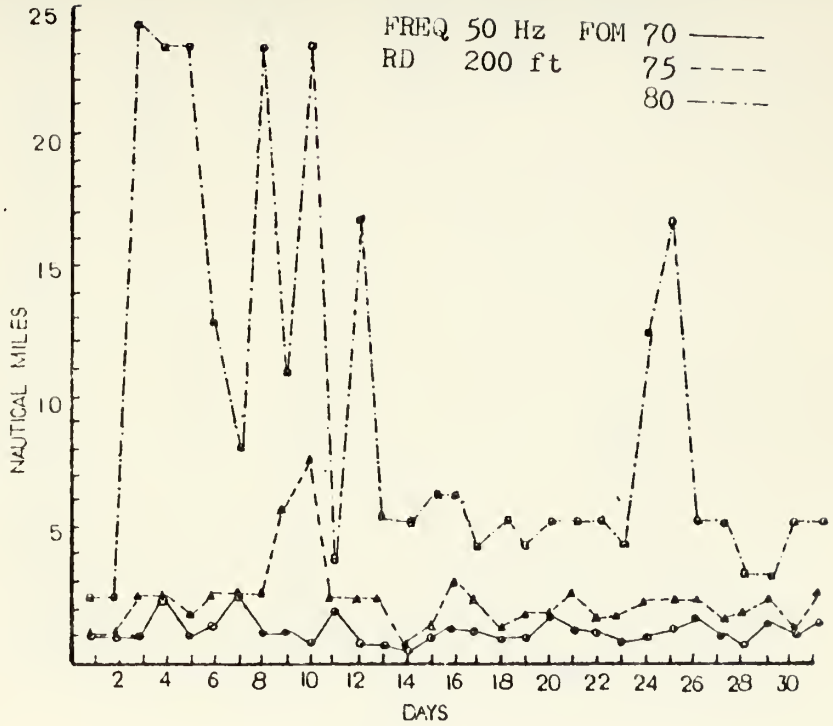


Figure 35

Median detection range (MDR) versus time for EOTS-FACT analysis: Comparison of FOM's of 70 dB, 75 dB, at 50 Hz and receiver at 200 feet.

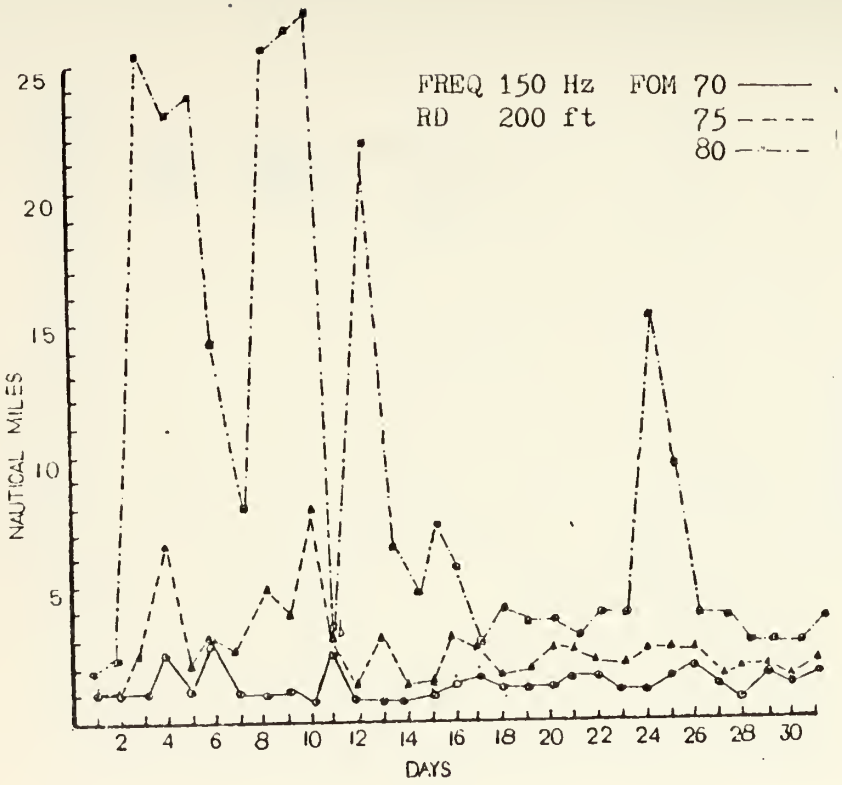


Figure 36

Median detection range (MDR) versus time for EOTS-FACT analysis: Comparison of FOM's of 70 dB, 75 dB, and 80 dB, at 150 Hz and receiver at 200 feet.

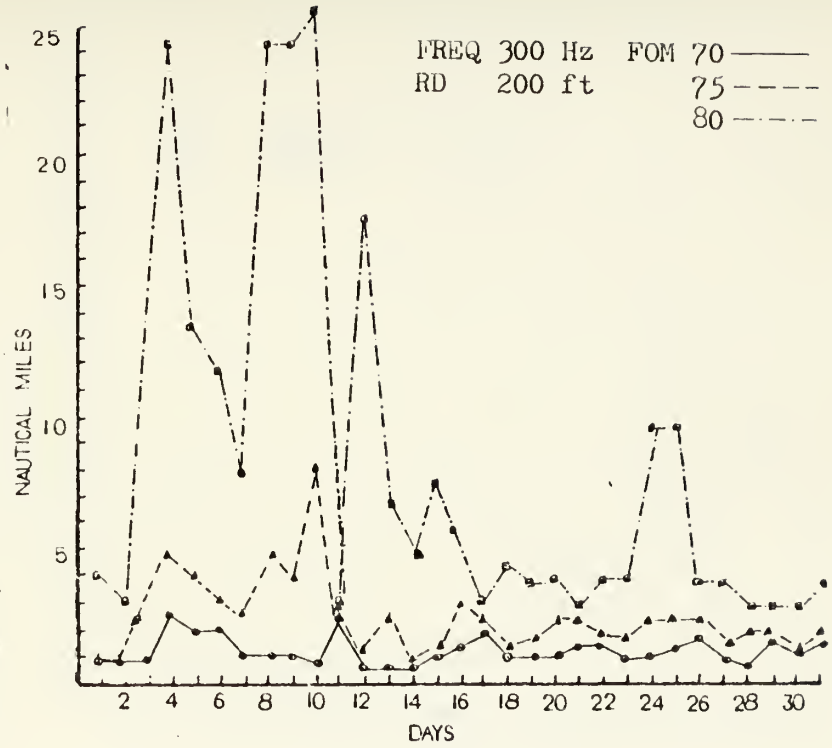


Figure 37

Median detection range (MDR) versus time for EOTS-FACT analysis: Comparison of FOM's of 70 dB, 75 dB, and 80 dB, at 300 Hz and receiver at 200 feet.

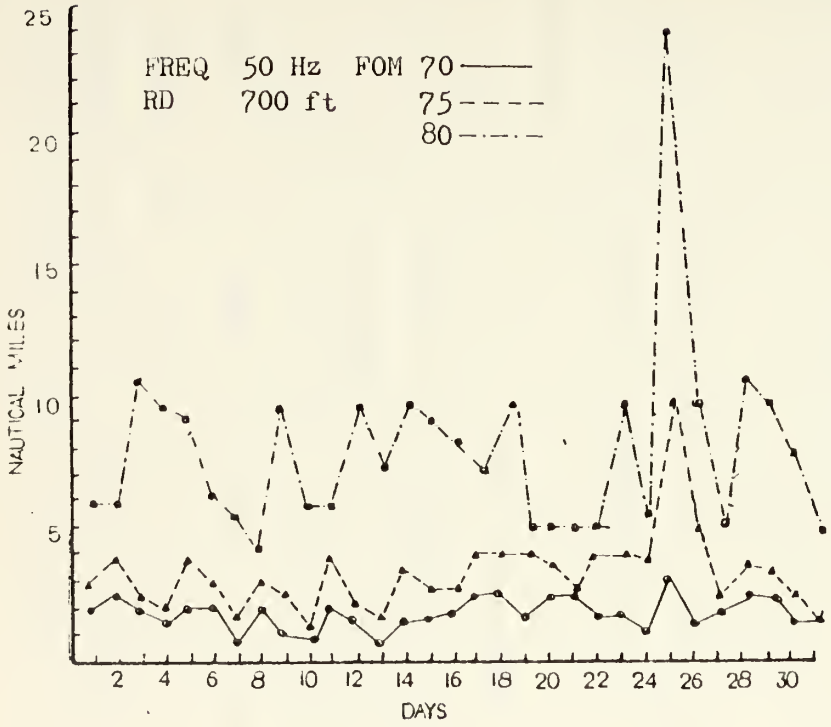


Figure 38

Median detection range (MDR) versus time for EOTS-FACT analysis: Comparison of FOM's of 70 dB, 75 dB, and 80 dB, at receiver depth of 700 feet and frequency of 50 Hz.

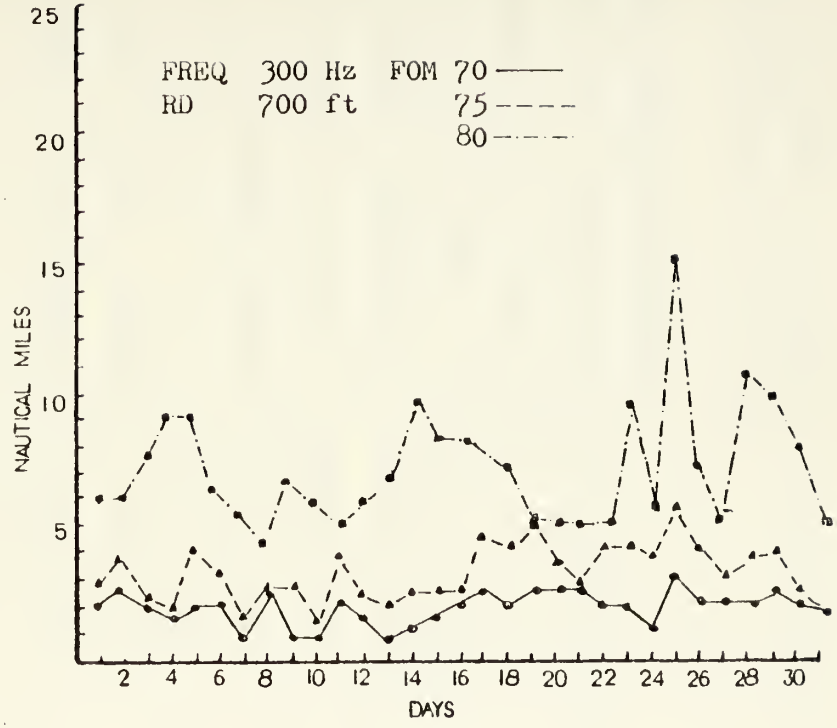


Figure 39

Median detection range (MDR) versus time for EOTS-FACT analysis: Comparison of FOM's of 70 dB, 75 dB, and 80 dB, at receiver depth of 700 feet and frequency of 300 Hz.

at 70 dB FOM, began to emerge at 75 dB FOM and were dramatic at 80 dB FOM (Figs. 20, 22, 24).

B. ODT-FACT ACOUSTIC ANALYSIS

The following observations are noted for the ODT-FACT acoustic output for 1-28 May 1980.

At 70 dB FOM the MDR is virtually constant, with slight frequency effects emerging at a fixed receiver depth (Fig. 40). As the receiver depth is lowered from 200 feet to 700 feet the corresponding change in MDR is less than one nautical mile for the analysis. As in the EOTS-FACT experiment, the ODT-FACT system appears somewhat insensitive to the low FOM.

As the FOM is increased to 75 dB at the 200 foot receiver depth, the overall day-to-day variability of MDR is increased (Fig. 41). As frequency is increased (Fig. 41), MDR again increases which is consistent with the half channel mode of the FACT model for prescribed frequencies and source/receiver depths [Spofford, 1974]. As the receiver is lowered to 700 feet, the overall variability of MDR throughout the month is minimal (Fig. 42). Moreover, the frequency effects present in figure 41 are not as dramatic as in figure 42.

At 80 dB FOM at the 200 foot receiver depth, the variability of MDR is very much a function of frequency (Fig. 43). The half channel mode, surface duct mode and possible surface image interference resulted in higher frequencies corresponding to higher median detection ranges. As the receiver depth was

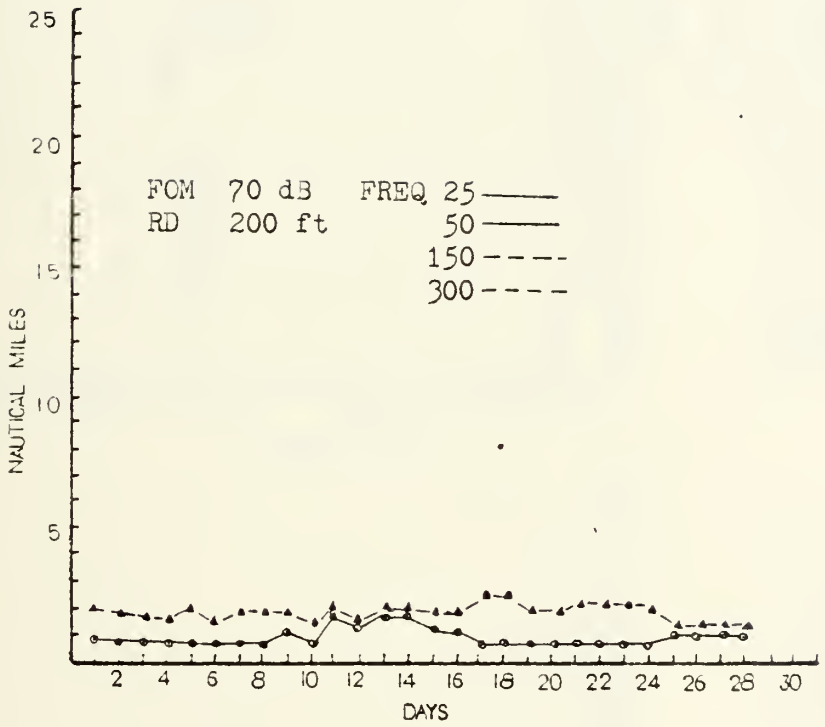


Figure 40

Median detection range (MDR) versus time for the ODT-FACT analysis: FOM of 70 dB, receiver depth of 200 feet, frequency range of 25 Hz, 50 Hz, 150 Hz, 300 Hz.

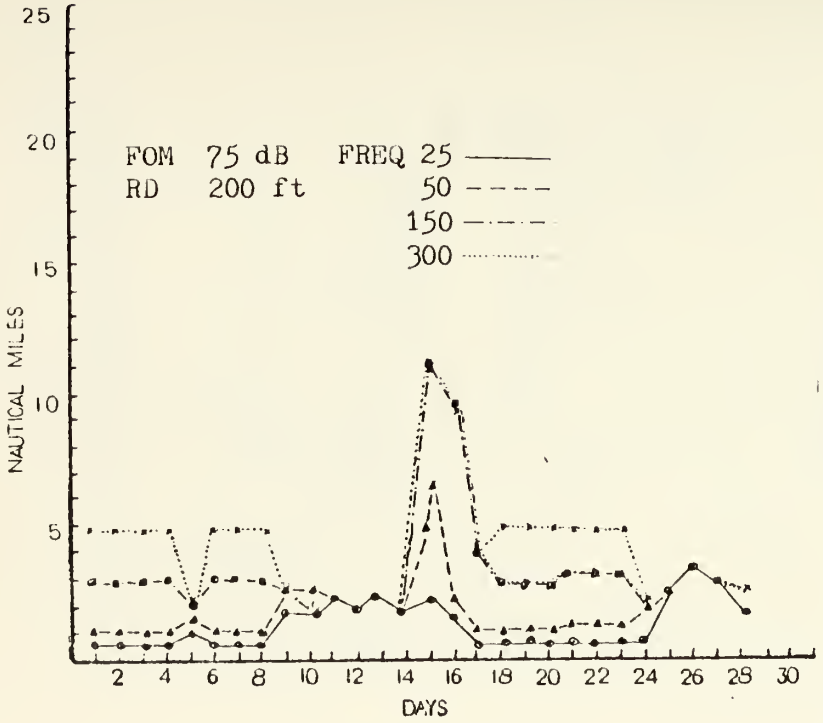


Figure 41

Median detection range (MDR) versus time for the ODT-FACT analysis: FOM of 75 dB, receiver depth of 200 feet, frequency range of 25 Hz, 50 Hz, 150 Hz, 300 Hz.

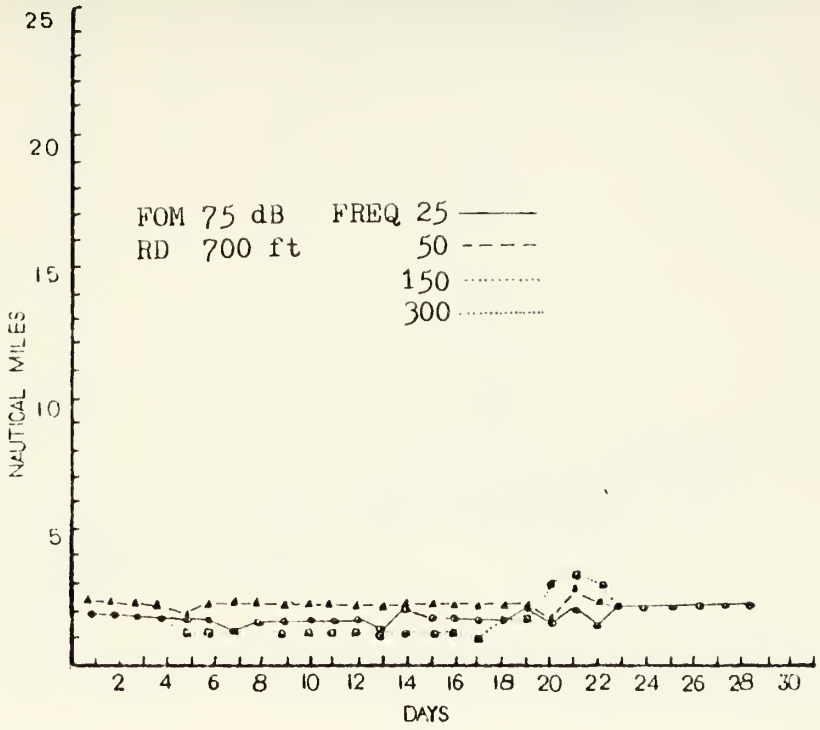


Figure 42

Median detection range (MDR) versus time for the ODT-FACT analysis: FOM of 75 dB, receiver of 700 feet, frequency range of 25 Hz, 50 Hz, 150 Hz, 300 Hz.

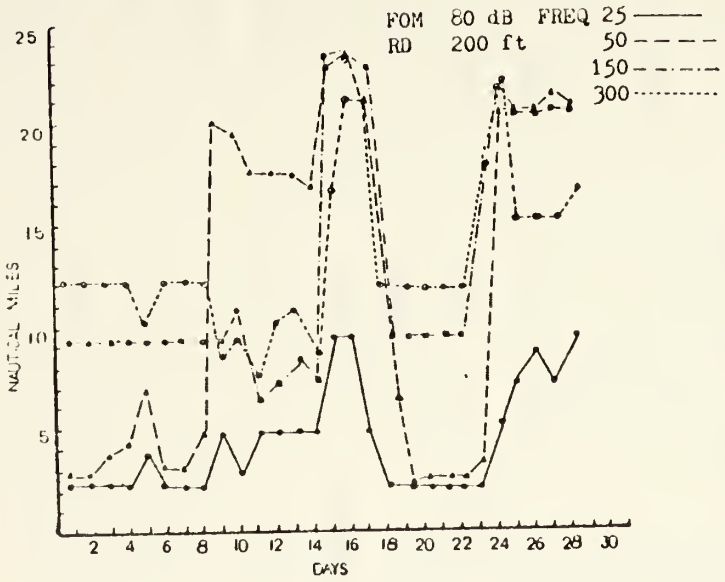


Figure 43

Median detection range (MDR) versus time for the ODT-FACT analysis: FOM of 80 dB, receiver depth of 200 feet, frequency range of 25 Hz, 50 Hz, 150 Hz, 300 Hz.

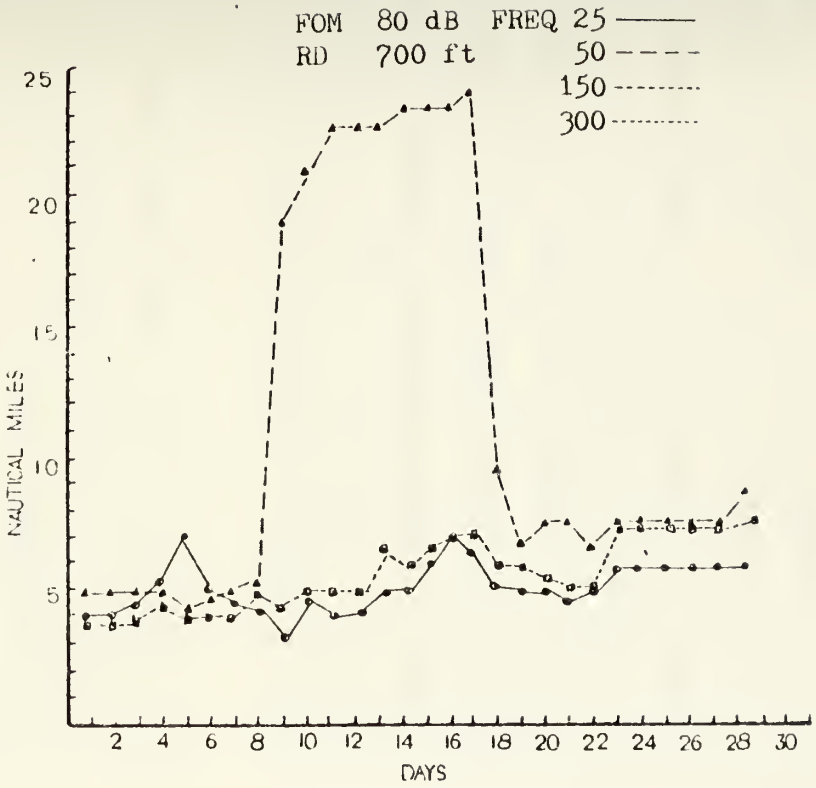


Figure 44

Median detection range (MDR) versus time for the ODT-FACT analysis: FOM of 80 dB, receiver depth of 700 feet, frequency range of 25 Hz, 50 Hz, 150 Hz, 300 Hz.

lowered to 700 feet, the MDR variability throughout the month was minimal except for the 50 Hz frequency (Fig. 44). Surface image interference could possibly account for this. Another possibility involves potential problems in the FACT model when either the source or receiver is in the region of the duct formation [FNOC, 1981]. Figures 43 and 44 show that frequency effects are significantly reduced as receiver depth changes from 200 feet to 700 feet. When the receiver was moved to 12770 feet (near bottom), the MDR did not vary for the entire month.

For this experiment, as the receiver varied from 200 to 700 feet, both the mean MDR as well as the standard deviation changed (Table 1). In basic agreement with the EOTS-FACT results, there was less subjective day-to-day acoustic variability at the deeper receiver depth. As a function of frequency, the 25-50 Hz data revealed a higher MDR at the deeper receiver depth (700 feet) while the 150-300 Hz data showed a higher MDR at the 200 foot receiver (Figs. 45-48) at 80 dB FOM. As the FOM is decreased to 75 dB, the same result is evident (Figs. 49-52). Generally, however the overall acoustic variability and sensitivity to frequency and receiver depth is dominated by the choice of FOM. As in the previous analysis, a much greater day-to-day acoustic variability, both as a function of frequency and receiver depth, is evident at 80 dB FOM.

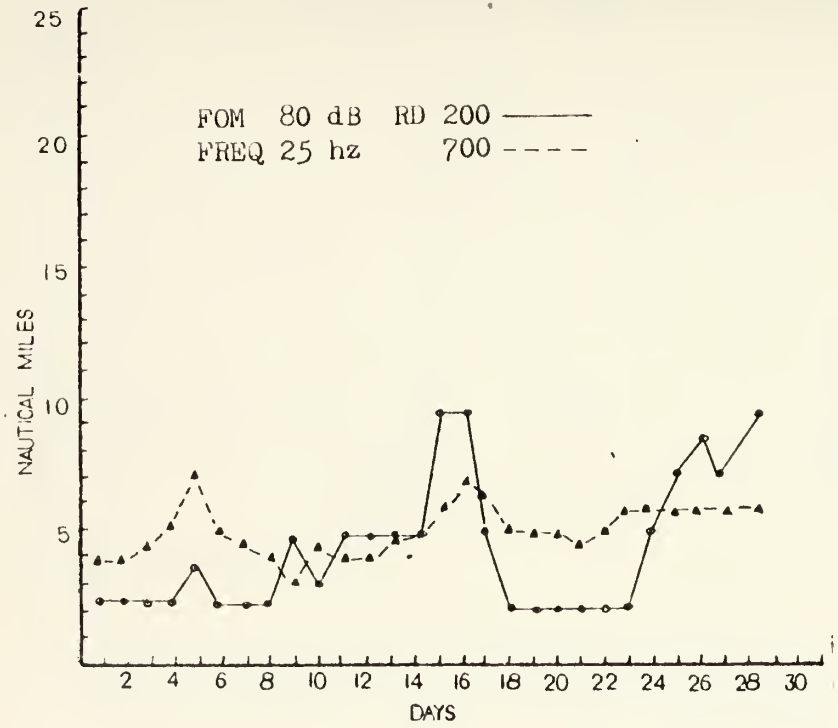


Figure 45

Median detection range (MDR) versus time for the ODT-FACT analysis: Comparison of 200 foot receiver to 700 foot receiver at 25 Hz at a FOM of 80 dB.

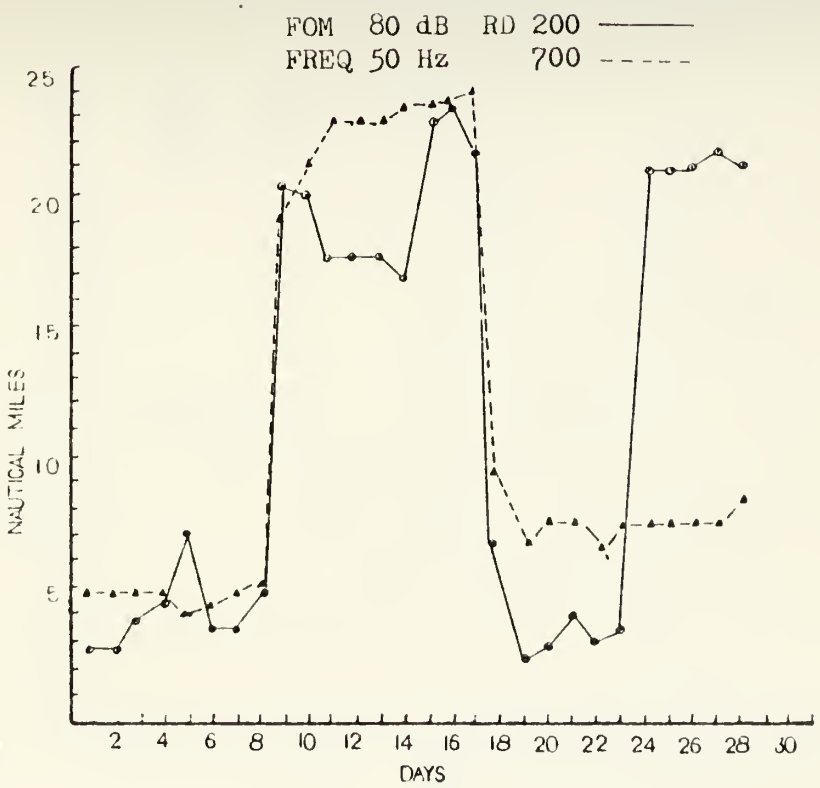


Figure 46

Median detection range (MDR) versus time for the ODT-FACT analysis: Comparison of 200 foot receiver to 700 foot receiver at 50 Hz at a FOM of 80 dB.

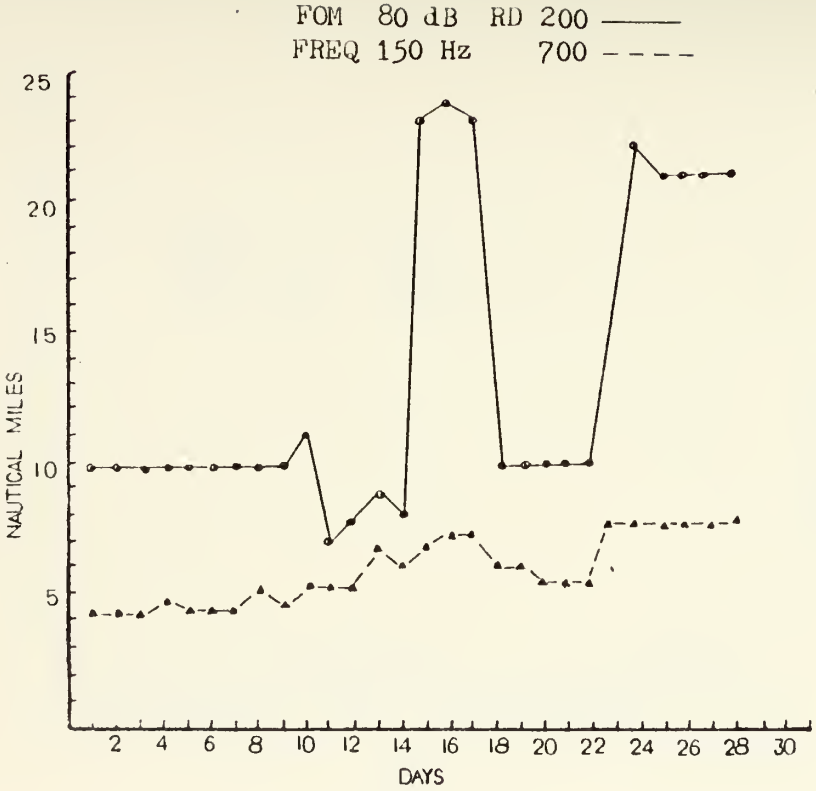


Figure 47

Median detection range (MDR) versus time for the ODT-FACT analysis: Comparison of 200 foot receiver to 700 foot receiver at 150 Hz at a FOM of 80 dB.

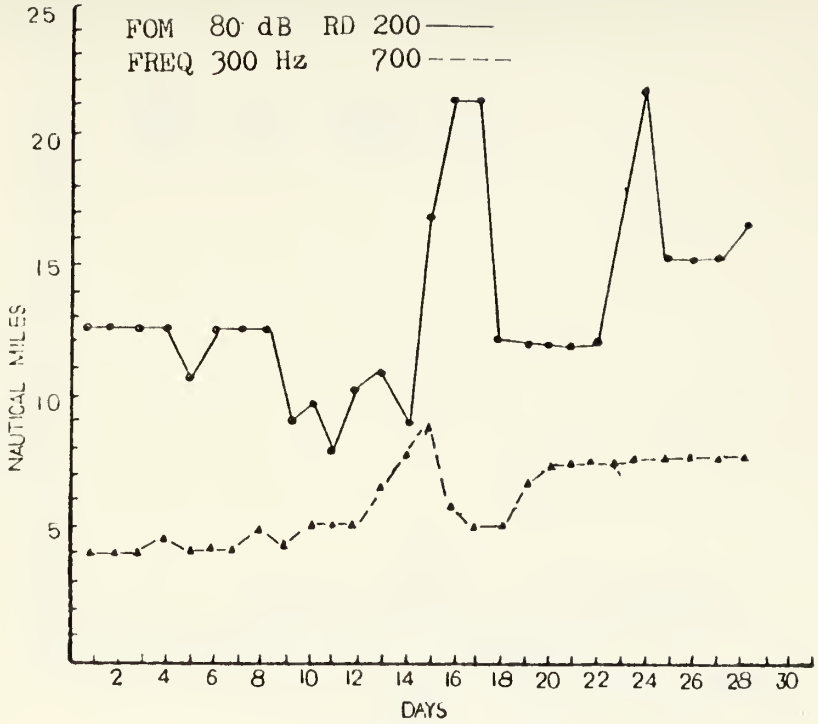


Figure 48

Median detection range (MDR) versus time for the ODT-FACT analysis: Comparison of 200 foot receiver to 700 foot receiver at 300 Hz at a FOM of 80 dB.

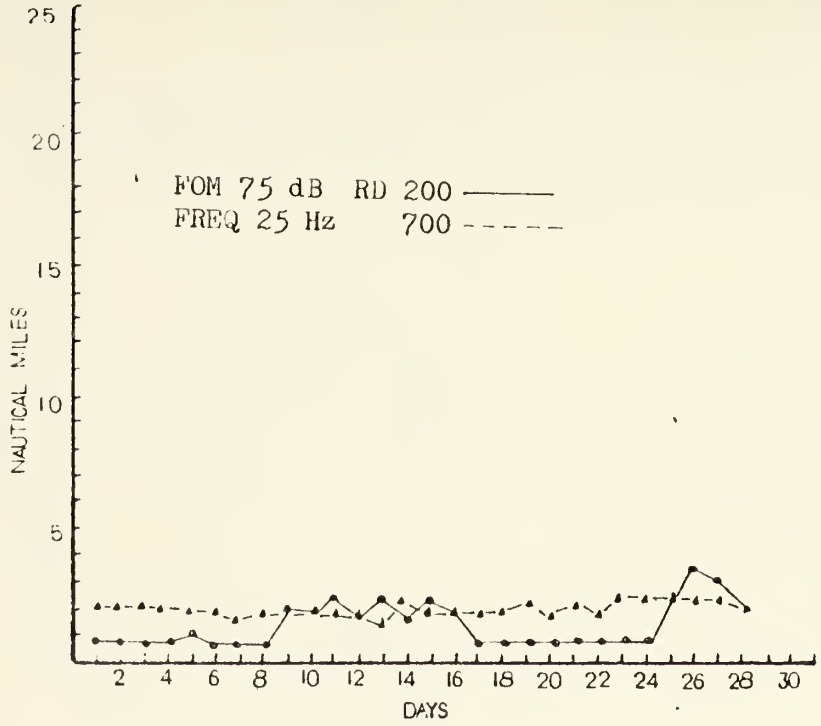


Figure 49

Median detection range (MDR) versus time for the ODT-FACT analysis: Comparison of 200 foot receiver to 700 foot receiver at 25 Hz at a FOM of 75 dB.

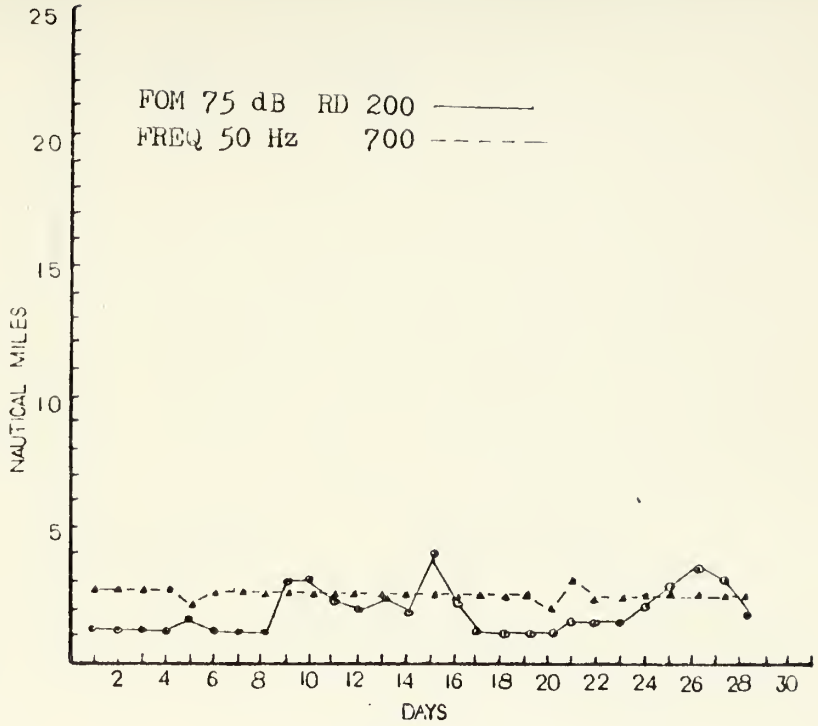


Figure 50

Median detection range (MDR) versus time for the ODT-FACT analysis: Comparison of 200 foot receiver to 700 foot receiver at 50 Hz at a FOM of 75 dB.

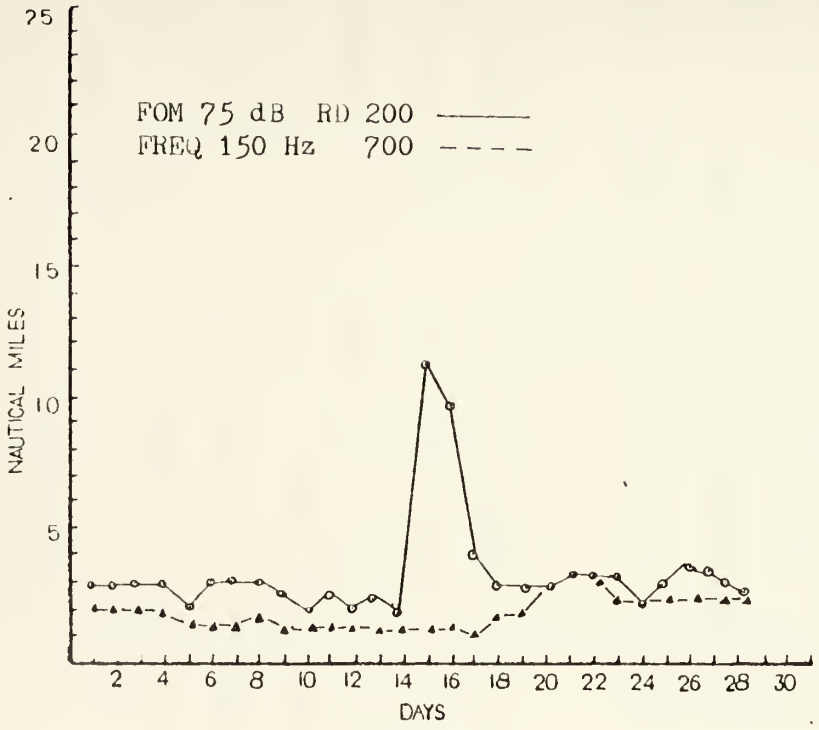


Figure 51

Median detection range (MDR) versus time for the ODT-FACT analysis: Comparison of 200 foot receiver to 700 foot receiver at 150 Hz at a FOM of 75 dB.

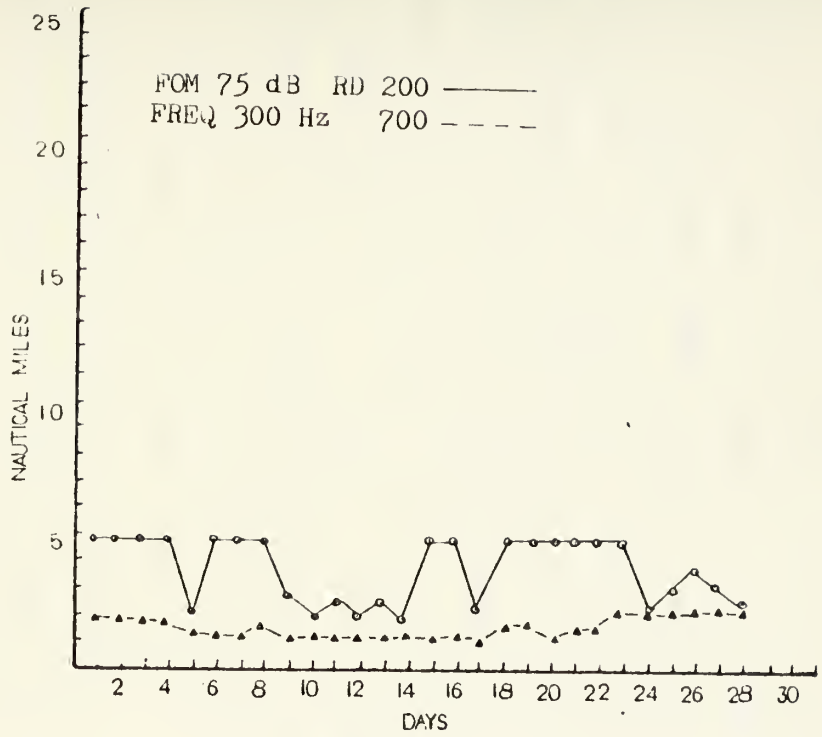


Figure 52

Median detection range (MDR) versus time for the ODT-FACT analysis: Comparison of 200 foot receiver to 700 foot receiver at 300 Hz at a FOM of 75 dB.

Overall, the ODT-FACT acoustic analysis exhibited somewhat similar effects to those discussed in the EOTS-FACT analysis. As the FOM is increased, MDR variance increased regardless of other parameter sensitivities. The time series analysis shows that although the EOTS-FACT system is statistically very similar to the ODT-FACT system (Table 1), the ODT-FACT median detection range does not vary nearly as much on a day-to-day basis (Fig. 43). That is, the ODT-FACT time series tends to stabilize for a synoptic period (3-5 days), undergo a change, then restabilize. The EOTS-FACT system reflected much more daily variation in MDR. [Fig. 24]

As with the EOTS-FACT system, the ODT-FACT data indicates that overall MDR variability based on time series analysis decreases as receiver depth is increased regardless of FOM (Figs. 53-58). This is logical considering that more rapid oceanographic changes occur in the near surface regions.

C. BT-FACT ACOUSTIC ANALYSIS

The following acoustic observations are noted for the BT-FACT output for the available BT's during 1-29 May 1980. The BT readings were obtained from FNOC and were the only BT's that entered the EOTS system for OWS Papa during the experimental time period. Unfortunately, BT readings were not available for everyday of the month. Six days were missing because no observations were passed to FNOC for those days. The BT's were received in a computerized message format and directly input to the FACT model in a point analysis.

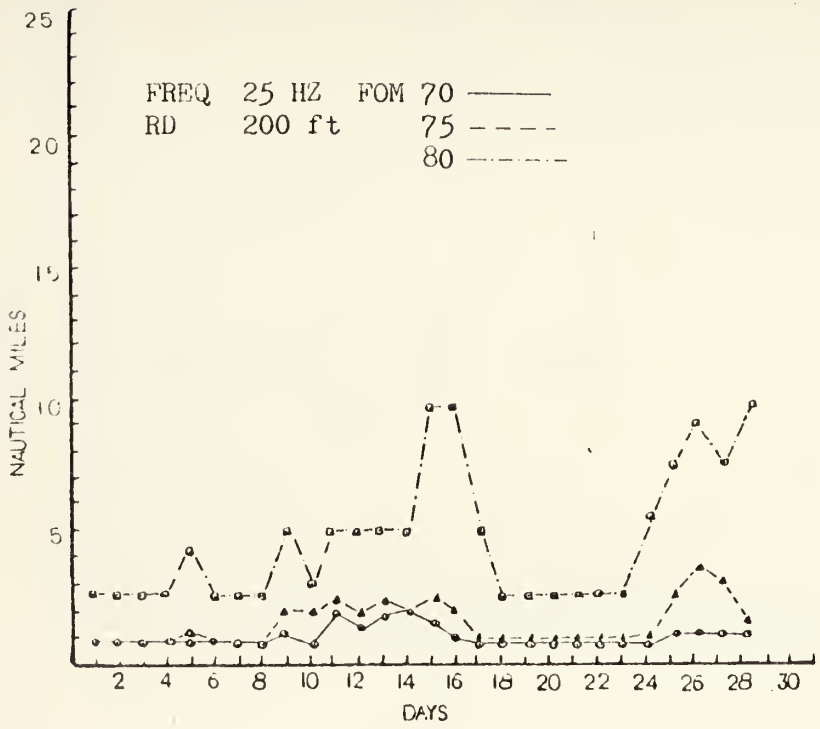


Figure 53

Median detection range (MDR) versus time for the ODT-FACT analysis: Comparison of FOM's of 70 dB, 75 dB, and 80 dB, at 25 Hz and receiver depth of 200 feet.

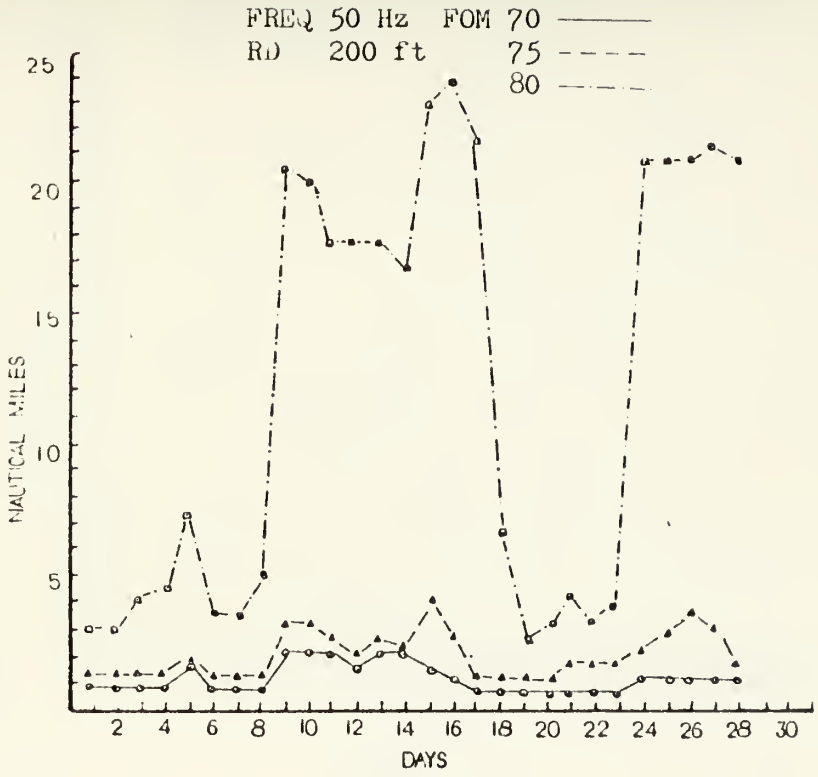


Figure 54

Median detection range versus time for the ODT-FACT analysis: Comparison of FOM's of 70 dB, 75 dB, and 80 dB, at 50 Hz and receiver depth of 200 feet.

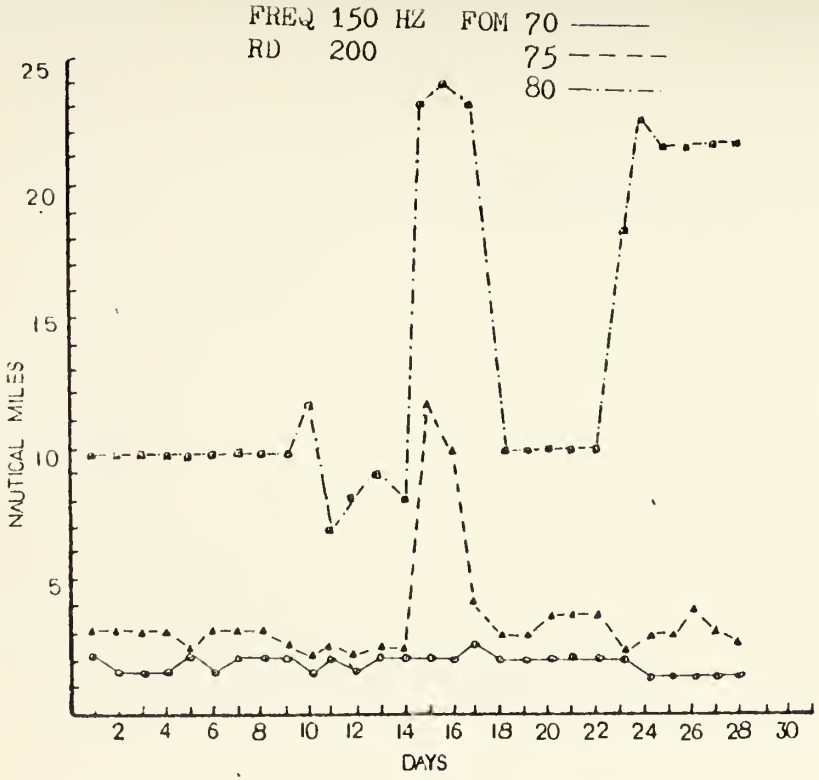


Figure 55

Median detection range (MDR) versus time for the ODT-FACT analysis: Comparison of FOM's of 70 dB, 75 dB, and 80 dB, at 150 Hz and receiver depth of 200 feet.

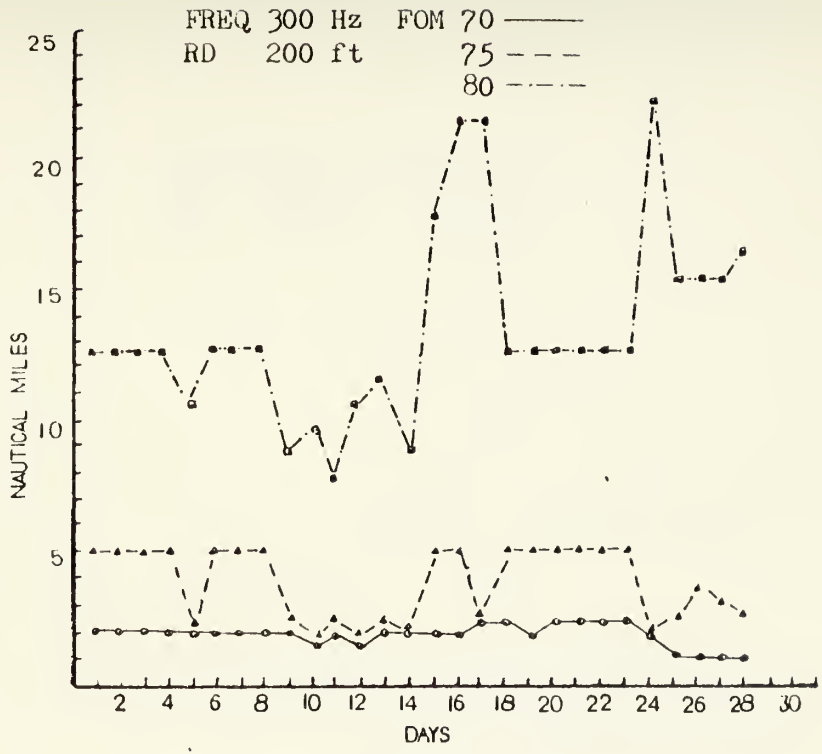


Figure 56

Median detection range (MDR) versus time for the ODT-FACT analysis: Comparison of FOM's of 70 dB, 75 dB, and 80 dB, at 300 Hz and receiver depth of 200 feet.

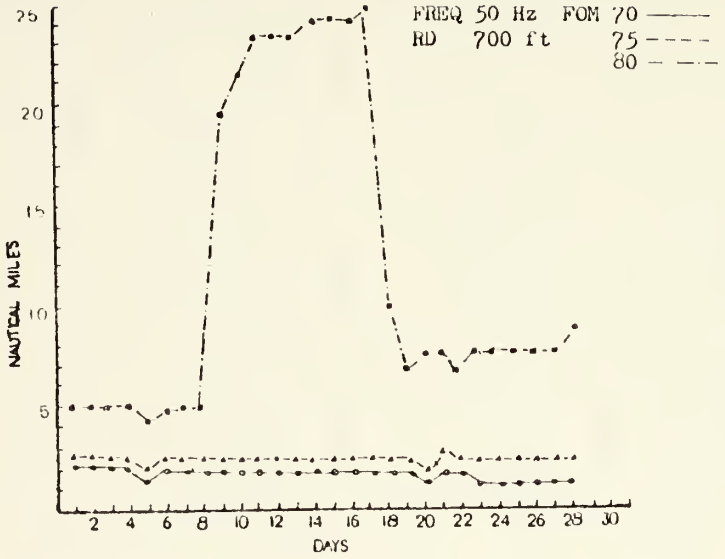


Figure 57

Median detection range (MDR) versus time for the ODT-FACT analysis: Comparison of FOM's of 70 dB, 75 dB, and 80 dB, at 50 Hz and receiver depth of 700 feet.

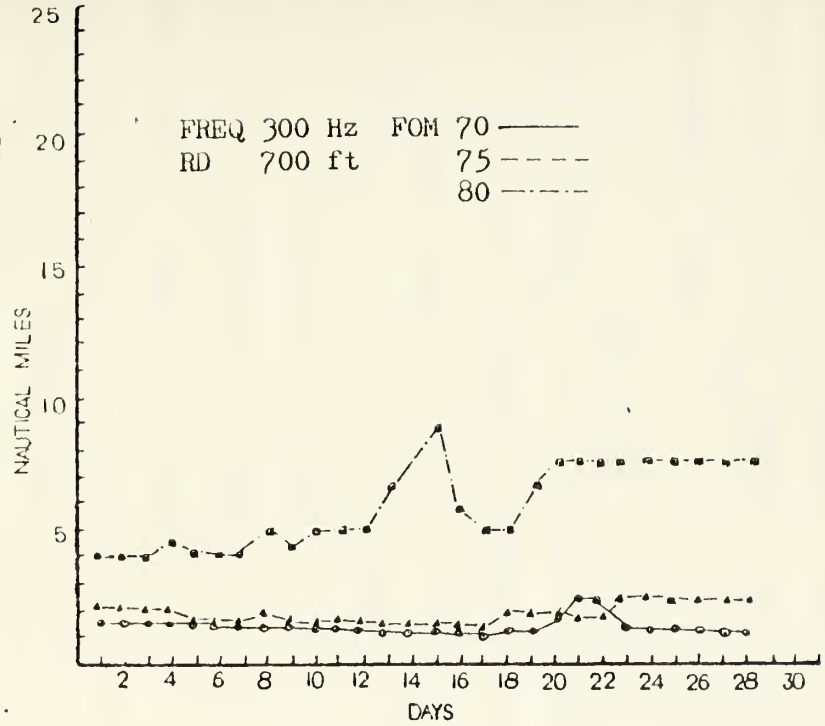


Figure 58

Median detection range (MDR) versus time for the ODT-FACT analysis: Comparison of FOM's of 70 dB, 75 dB, and 80 dB, at 300 Hz and receiver depth of 700 feet.

At 70 dB FOM as with the previous two analyses, the FACT accuracy limitation of half a nautical mile did not allow more precise measurements (Fig. 59). At a receiver depth of 200 feet, MDR was constant, regardless of frequency (Fig. 59).

As the FOM is increased to 75 dB at a receiver depth of 200 feet, the day-to-day variance of MDR increases (Fig. 60), but not to the extent observed in the previous model system analyses. MDR remains relatively constant at the low frequencies (25-50 Hz), but as frequency increases (150-300 Hz) the actual MDR as well as the variability of MDR increases (Fig. 60) at the 200 foot receiver depth. Evaluation of the sound velocity profiles shows strong subsurface ducting in which both the source and receiver are interacting, which could account for increasing MDR with increasing frequency.

At 80 FOM at the 200 foot receiver depth, the variability of MDR increased, but not to the extent as in the previous two analyses (Fig. 61). The variance of MDR is also much more a visible function of frequency (Fig. 61). At 50 Hz, the variance of MDR for the entire month was from .5 to 13 nautical miles, much less than in either previous analyses. The variance of MDR at 300 Hz also had a range of from .5 to 13 nautical miles. However the day-to-day variance at 300 Hz was much more significant than at 50 Hz (Fig. 61). For the 700 foot receiver depth, the increased range and variability of MDR appears much more dramatic at 80 dB FOM than at 75 dB FOM (Figs. 62, 63). At higher frequencies (150-300 Hz) the

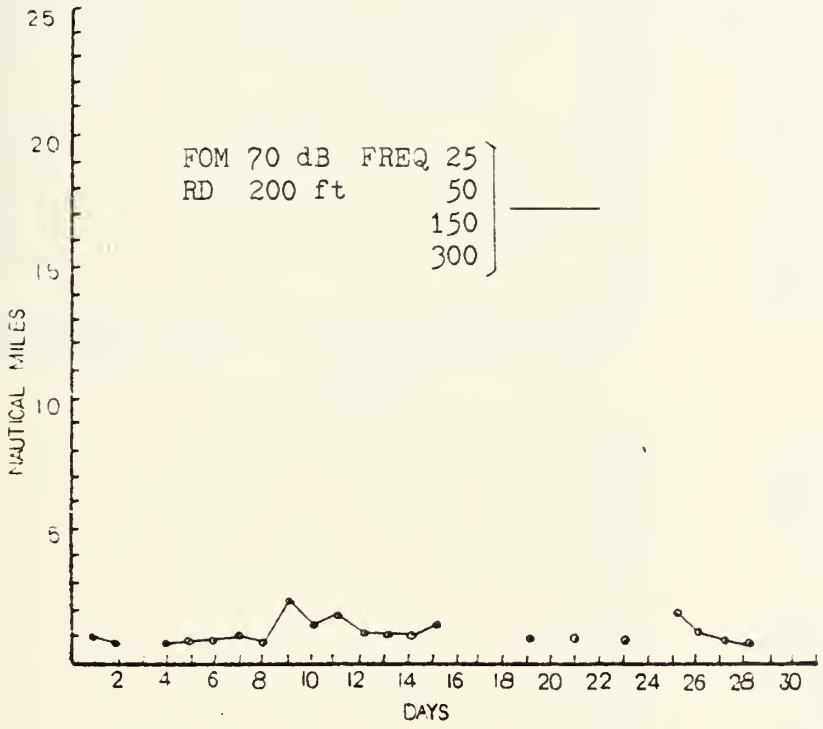


Figure 59

Median detection range (MDR) versus time for the BT-FACT analysis: FOM of 70 dB, receiver depth of 200 feet, and frequency range of 25 Hz, 50 Hz, 150 Hz, 300 Hz.

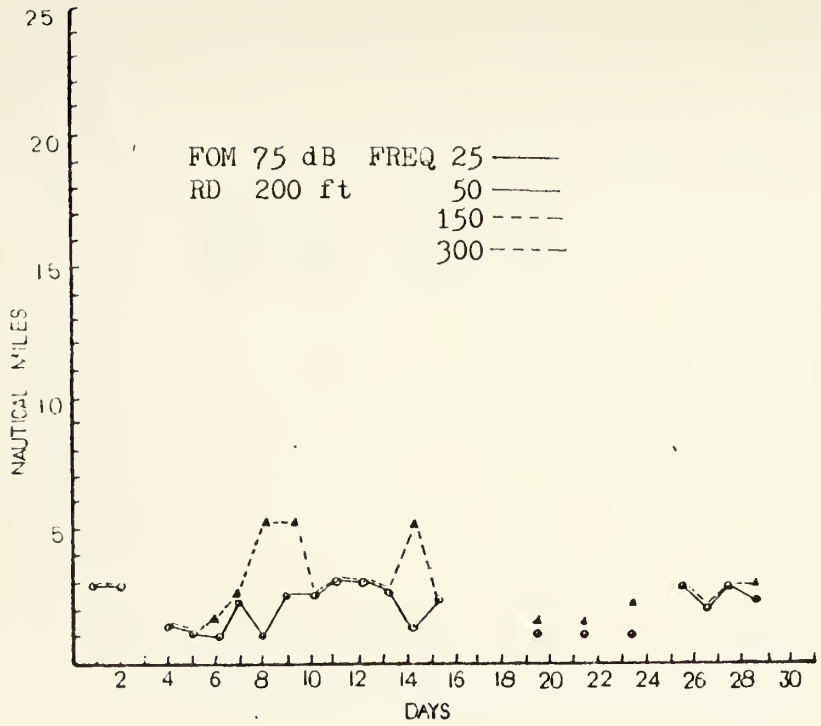


Figure 60

Median detection range (MDR) versus time for the BT-FACT analysis: FOM of 75 dB, receiver depth of 200 feet, and frequency range of 25 Hz, 50 Hz, 150 Hz, 300 Hz.

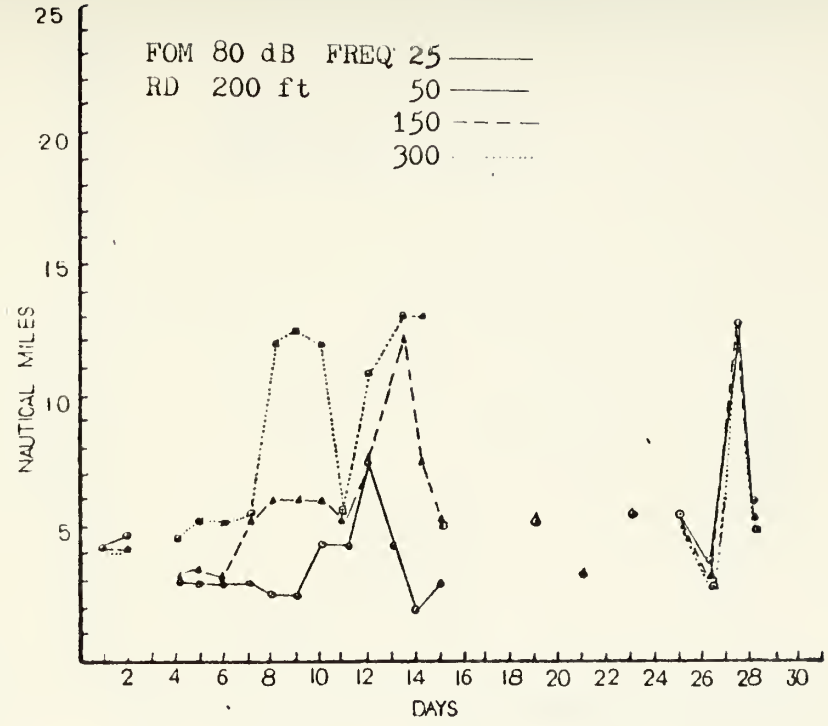


Figure 61

Median detection range (MDR) versus time for the BT-FACT analysis: FOM of 80 dB, receiver depth of 200 feet, and frequency range of 25 Hz, 50 Hz, 150 Hz, 300 Hz.

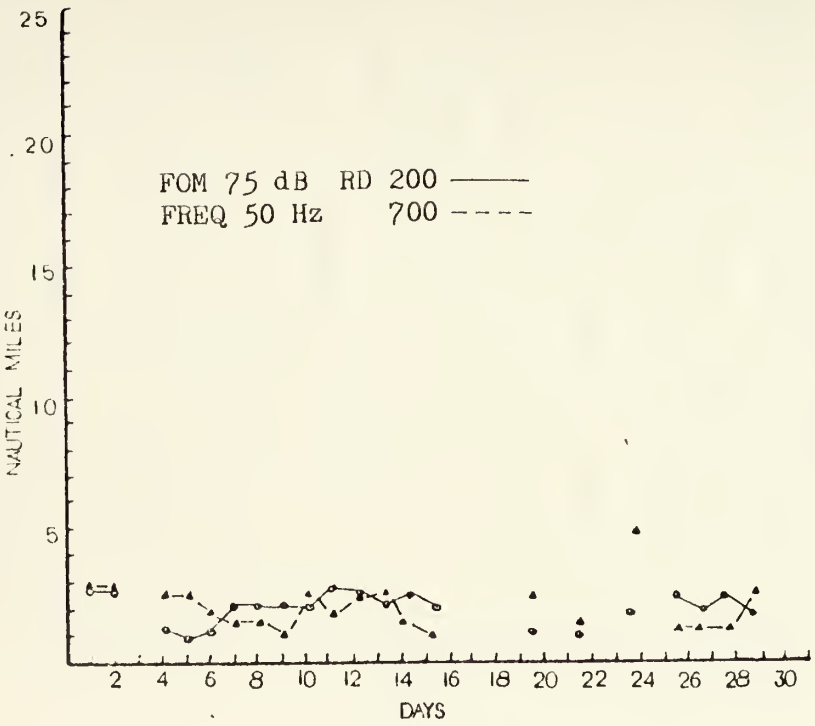


Figure 62

Median detection range (MDR) versus time for the BT-FACT analysis: Comparison of 200 foot receiver with 700 foot receiver for FOM of 75 dB at 50 Hz.

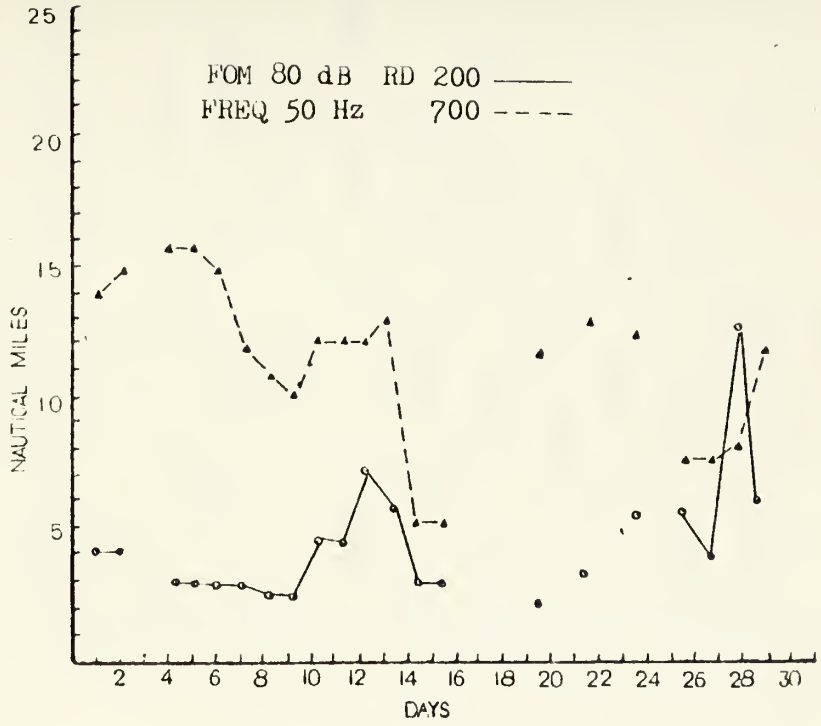


Figure 63

Median detection range (MDR) versus time for the BT-FACT analysis: Comparison of 200 foot receiver with 700 foot receiver for FOM of 80 dB at 50 Hz.

range and variance of the MDR (Fig. 64) is less at the 700 foot receiver than at the 200 foot receiver, (Table 2). At low frequencies (25-50 Hz) a greater MDR as well as greater MDR variability is evident (Fig. 63) at the 700 foot receiver depth (Table 2). At the near bottom receiver (12,770 feet), the results were identical to those obtained with EOTS-FACT and ODT-FACT. All three systems gave identical results (11 mile MDR) for the near bottom receiver.

The BT-FACT analysis displays less variance, more continuity and fewer anomalies than either EOTS-FACT or ODT-FACT. The effects of FOM still dominate the analysis, but the magnitude of the effects are much reduced in comparison to the other analyses. Frequency effects (high/low) were more consistent and more important (visible) in the final analysis than in the previous two analyses. That is, in the BT-FACT analysis, the effects of FOM were greatly reduced in comparison to EOTS-FACT or ODT-FACT. Consequently, frequency effects and receiver placement had more of an effect in the BT-FACT (reference) analysis. Unlike the previous analyses, the BT-FACT data shows that the effects of FOM are also frequency dependent (Fig. 66-69). For example, at 300 Hz there is more variance at 80 FOM than at 50 Hz using 80 FOM (Fig. 66-69).

The overall acoustic variability exhibited in the BT-FACT experiment is much less than in the previous two analyses. This experiment leads one to believe that the ocean is relatively stable acoustically for passive low frequencies

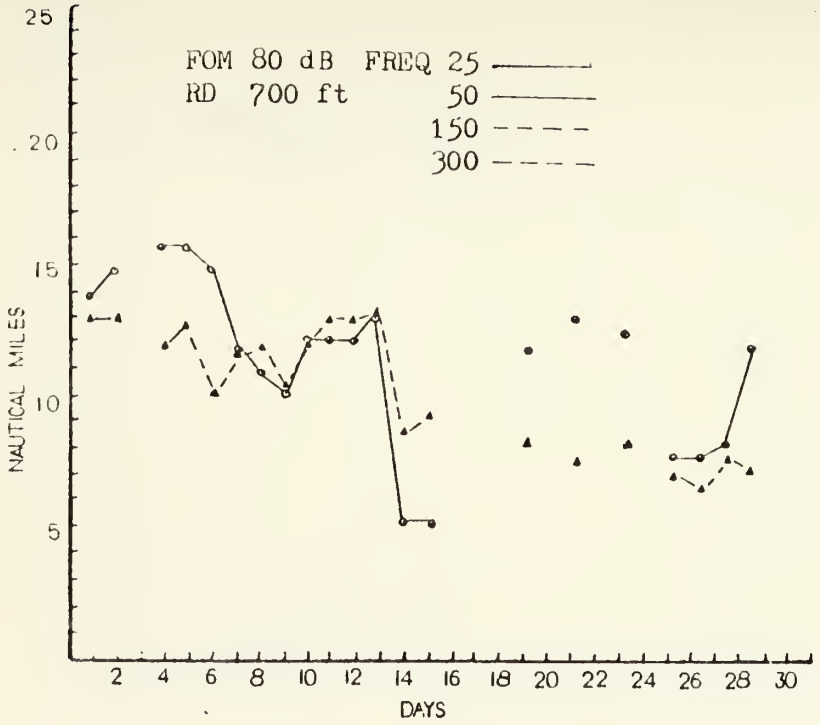


Figure 64

Median detection range (MDR) versus time for the BT-FACT analysis: FOM of 80 dB, receiver at 700 feet, frequency range of 25 Hz, 50 Hz, 150 Hz, 300 Hz.

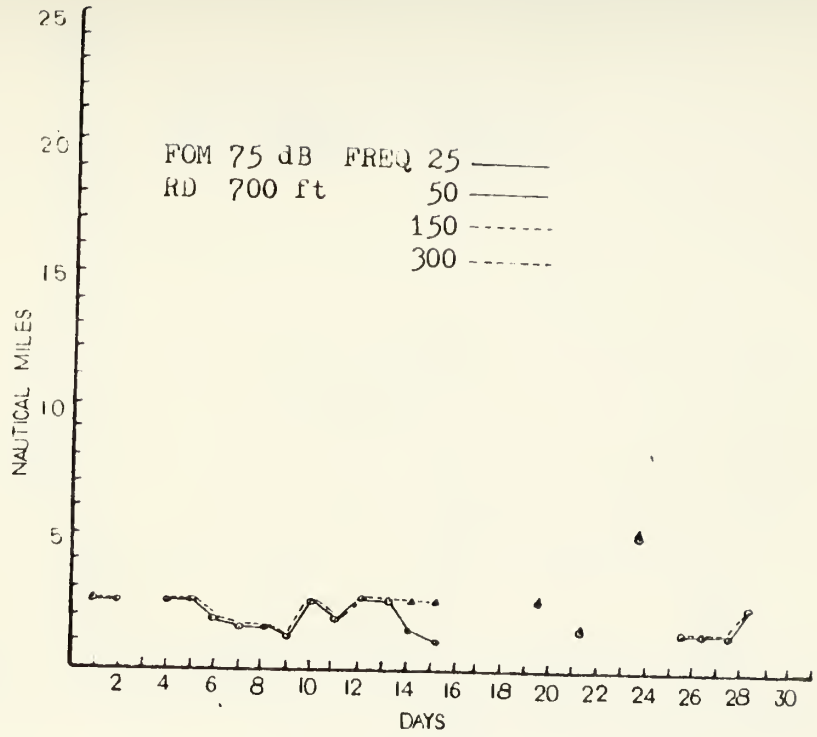


Figure 65

Median detection range (MDR) versus time for the BT-FACT analysis: FOM of 75 dB, receiver at 700 feet, frequency range of 25 Hz, 50 Hz, 150 Hz, 300 Hz.

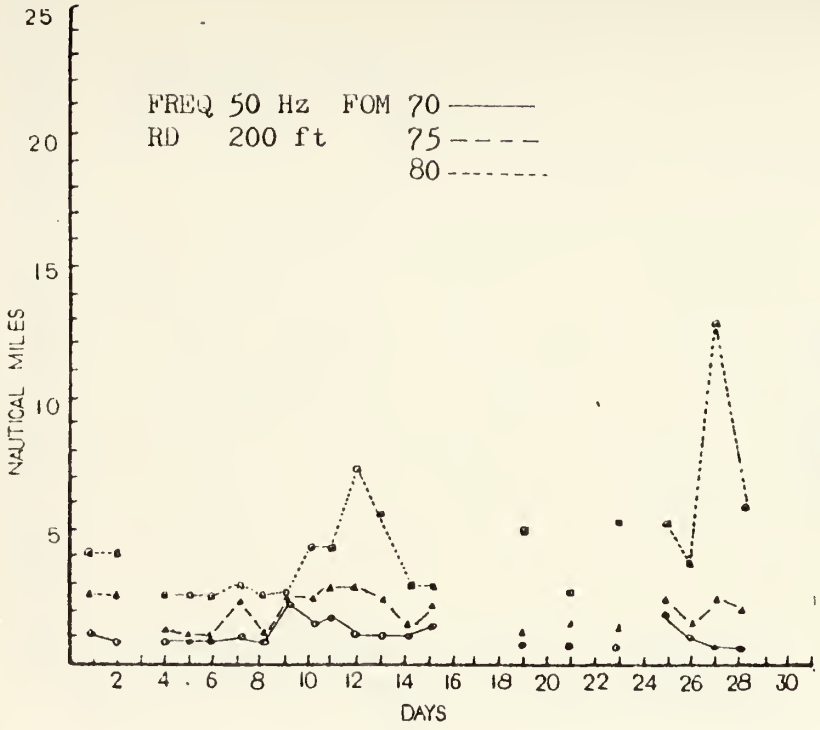


Figure 66

Median detection range (MDR) versus time for the BT-FACT analysis: Comparison of FOM's of 70 dB, 75 dB, and 80 dB for 200 foot receiver at 50 Hz.

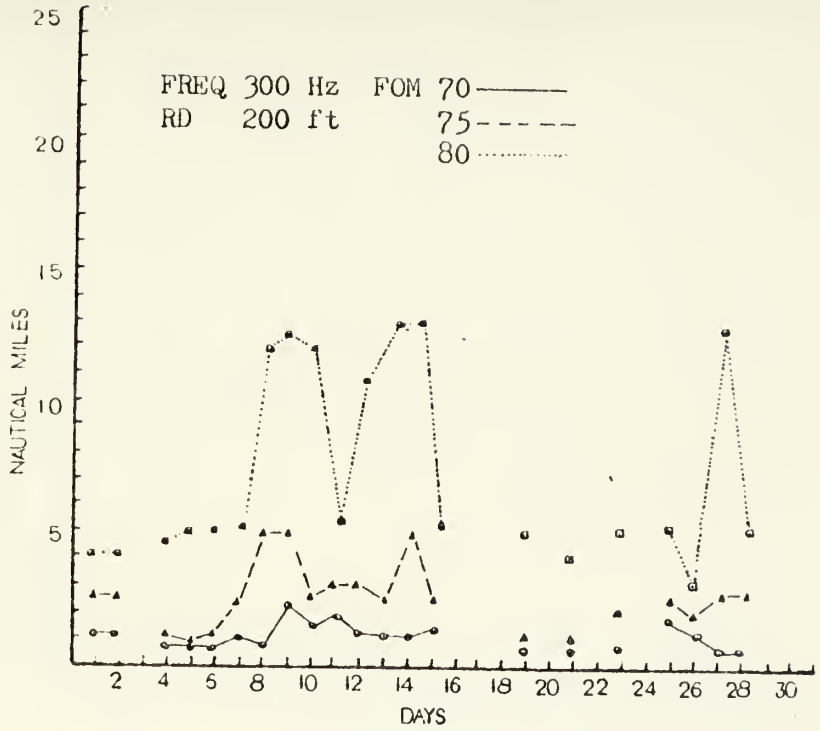


Figure 67

Median detection range (MDR) versus time for the BT-FACT analysis: Comparison of FOM's of 70 dB, 75 dB and 80 dB for 200 foot receiver at 300 Hz.

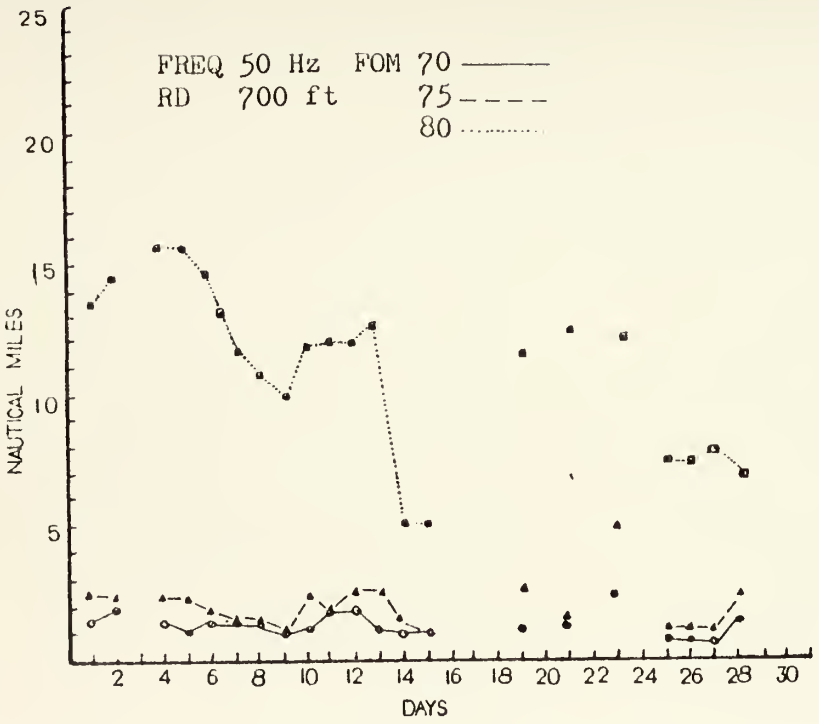


Figure 68

Median detection range (MDR) versus time for the BT-FACT analysis: Comparison of FOM's of 70 dB, 75 dB, and 80 dB for 700 foot receiver at 50 Hz.

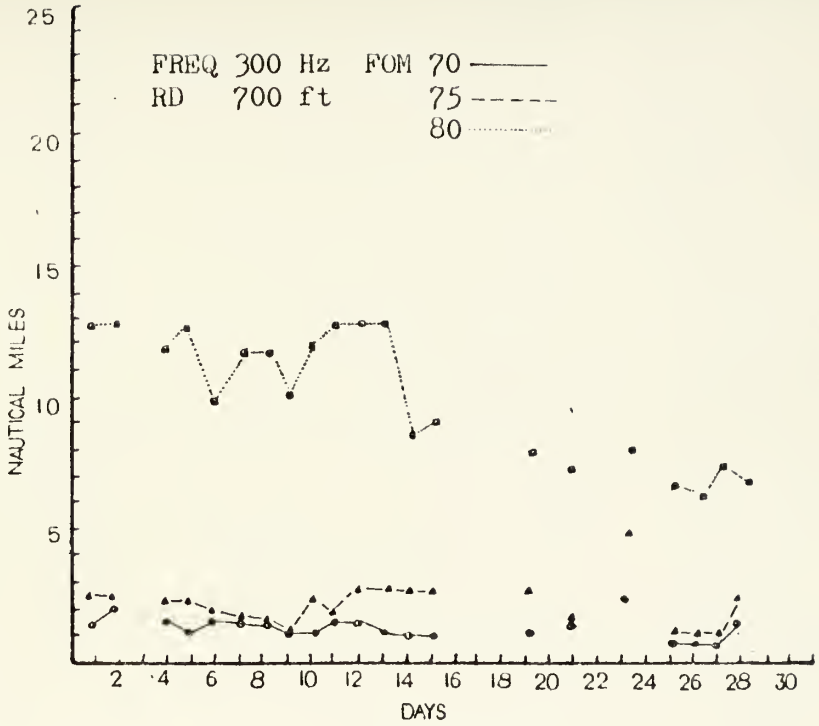


Figure 69

Median detection range (MDR) versus time for the BT-FACT analysis: Comparison of FOM's of 70 dB, 75 dB, and 80 dB for 700 foot receiver at 300 Hz.

over synoptic periods. Also as receiver depth is increased, the range of values for MDR and the overall acoustic variability decrease as is expected.

IV. DISCUSSION OF RESULTS

A. ACOUSTIC COMPARISON

Comparison of EOTS-FACT and ODT-FACT to the reference BT-FACT shows that the models indicate more acoustic variability (using MDR as the measure of effectiveness) than actual direct environmental (BT) input supports. This is reflected in review in Figure 70. At the 200 foot receiver depth for 50 Hz, a tremendous daily variation of MDR is observed in the EOTS-FACT product in relation to the minimal day-to-day change of MDR for the BT-FACT product. More marked is the change in actual variability at 300 Hz as compared to 50 Hz. This frequency dependence is not evidenced in the EOTS product due to the overwhelming variability present. This variability is reflected in several ways: (1) Figure of Merit, (2) frequency and (3) receiver depth.

1. FOM Effects

A change in the FOM caused the most acoustic variability (change in MDR), regardless of what system was analyzed. This was due to the fact that at higher FOM's the slope of the propagation loss curve approached a critical region where a slight change of even 1 dB caused dramatic range changes.

After analyzing the EOTS-FACT output, it was observed that at 80 dB FOM, there was a tremendous variance of MDR

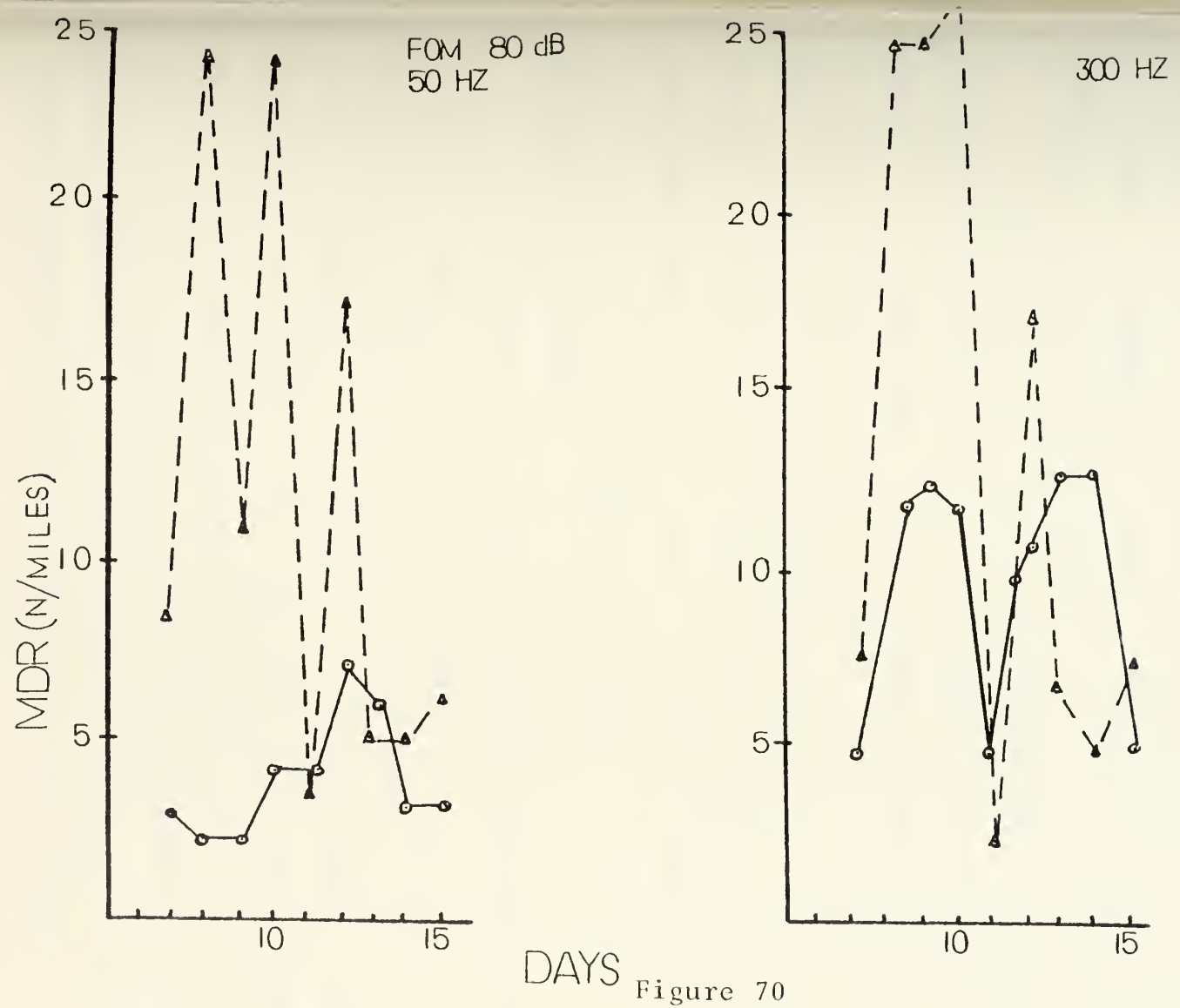


Figure 70

Median detection range (MDR) versus time: Comparison of EOTS-FACT to BT-FACT at 50 Hz and 300 Hz and receiver at 200 feet.

over a synoptic period. A significant variance, though less than in EOTS-FACT was also apparent in the analysis of the ODT-FACT system. The model systems (EOTS and ODT) tended to support the thesis that the ocean possibly was not acoustically stable at low frequencies as had been commonly thought. Analysis of the BT-FACT system showed that even at 80 FOM, the ocean was acoustically stable, at least much more so than the other model systems predicted.

Analysis of all three systems shows that the models are relatively insensitive at low FOM's and become hypersensitive at high FOM's. This further indicates that uncertainty in the FOM causes large day-to-day variances. This is seen in the BT-FACT data as well as the other model systems. Moreover, since FOM is itself determined by source level and noise level, uncertainty in these parameters will also result in dramatic range differences, causing major operational problems.

At low FOM's (70-75 dB), the models (EOTS-FACT and ODT-FACT) appear to adequately represent the acoustic variability present in the reference system (BT-FACT) (Figs. 71-72). However at 80 dB FOM, it is readily apparent that the above is no longer true. One reason for the agreement of all three models in this respect can be demonstrated by analysis of the propagation loss curve in general and its overall sensitivity to Figure of Merit. Spherical spreading yields a transmission loss according to the equation

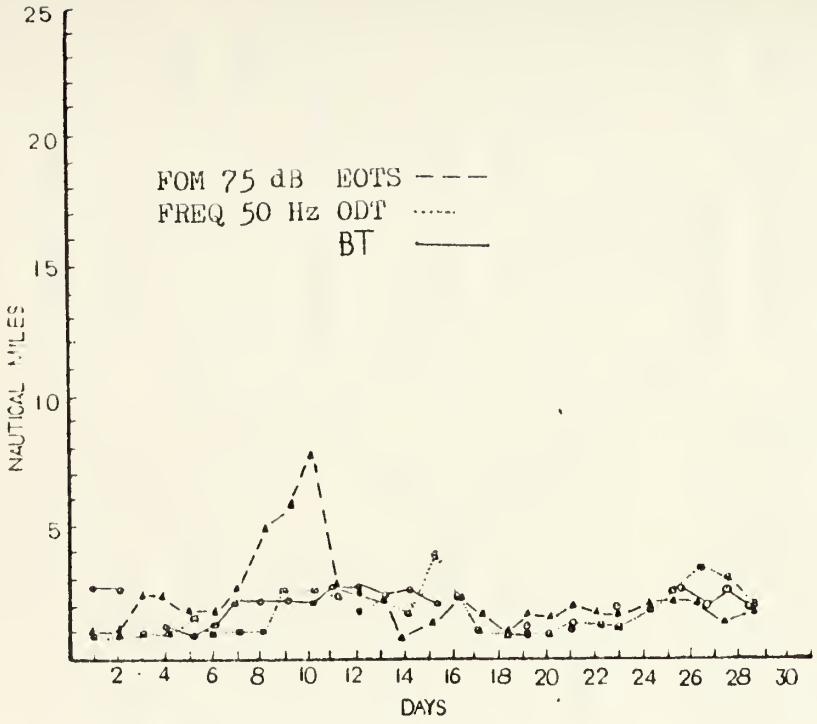


Figure 71

Median detection range (MDR) versus time: Comparison of EOTS-FACT and ODT-FACT to BT-FACT at 50 Hz and a FOM of 75 dB.

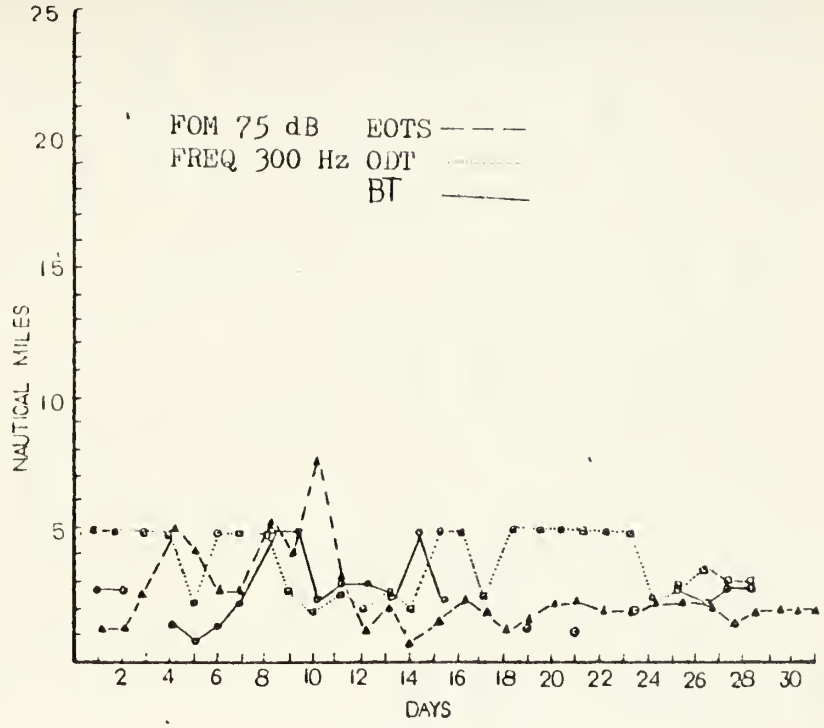


Figure 72

Median detection range (MDR) versus time: Comparison of EOTS-FACT and ODT-FACT to BT-FACT at 300 Hz and a FOM of 75 dB.

TL = 20 LOG R. At a distance of one mile from the source, this equates to approximately 64 dB, and at two miles from the source, TL is approximately 70 dB. This formula basically holds if we consider absorption and other loss mechanisms negligible for the low frequencies used in the analysis. It is evident that a 6 dB change in the FOM causes only a 1 nm change in MDR for this simplified case. Hence at low FOM's (around 70) very small changes in MDR are in general expected.

Based on FOM change alone, the models (EOTS and ODT) show a range of MDR from .5-25 nautical miles (somewhat frequency dependent) while the BT-FACT range (.5-13 nautical miles) is considerably less. EOTS-FACT showed the most variability with FOM and the BT-FACT showed the least variability. Most importantly, the impact of changing the FOM was constant and regardless of the system tested MDR variance increased with increased FOM.

A further insight is gained by looking at the time history of MDR (any case) as a function of FOM. The effects of FOM are present regardless of frequency, receiver depth, or varying thermal structure. Most of the MDR variability in the experiments resulted from a change in the FOM. A snapshot analysis will not reveal the variability dependence on FOM. Rather, only absolute differences appear which are not acoustically constant. A time series analysis is important to understand day-to-day-day or synoptic acoustic variability.

2. Frequency Effects

The BT-FACT system shows that instead of the four frequency (25, 30, 150, 300 Hz) variance that is present using EOTS-FACT or ODT-FACT, that high (150-300 Hz) and low (25-50 Hz) frequency effects are present. A change in frequency caused the least acoustic variance in the BT-FACT system even at 80 FOM, while both EOTS-FACT and ODT-FACT showed major frequency effects at 75 FOM.

Frequency effects throughout the analysis were a direct result of the input thermal structure. The largest MDR variance with frequency naturally occurs in all three experiments, at 80 dB FOM. EOTS-FACT showed the most variance with frequency as frequency was increased from 25 Hz to 300 Hz. At the 70 FOM, for all three experiments, the MDR results were virtually frequency independent.

A frequency anomaly apparent in all three experiments was that at high frequency (150-300 Hz), the MDR was greater than at low frequency (25-50 Hz) throughout much of the analysis. In transmission loss terms, lower frequencies were suffering more propagation loss than higher frequencies. Investigation of the FACT model showed that it is very sensitive to source/receiver placement, and that there are known low frequency cutoff problems as well as surface duct, half channel and surface image interference problems. Further analysis of the sound velocity structures revealed that the ODT-FACT model outputs were basically half channel, the

EOTS-FACT model showed some surface and subsurface ducting and the BT-FACT profiles displayed extensive subsurface ducting and possible convergence zone propagation. However, the fact that this frequency anomaly problem permeated the entire analysis regardless of the system tested indicates that an investigation should possibly be made into the FACT model in this regard. It is evident that the differing thermal structure/sound velocity profiles accounted for much of the acoustic differences in the results. The FACT model limitations described earlier (most notably the surface duct, surface image interference, and half channel modes) also contributed to anomalous frequency variations between the model systems as well as affecting the reference system. Frequency effects and depth effects are dependent on the input thermal structure, source/receiver depths, and the interplay of these parameters with known FACT model limitations. Again, a snapshot or single glimpse does not reveal the magnitude of the acoustic variability with respect to frequency changes and much more insight is gained by looking at a time series analysis.

3. Receiver Depth Effects

The most notable receiver depth effect is that for the deep receivers for all three experiments, both the range and variability of MDR decrease significantly (Table 1, 2). Also, the effects of changing frequencies is reduced at the 700 foot receiver. All three experiments indicate

ODT-FACT

req. (Hz)	FOM 70 RD 200	FOM 70 RD 700	FOM 75 RD 200	FOM 75 RD 700	FOM 80 RD 200	FOM 80 RD 700
5	.84/.56	1.36/.23	1.14/.83	2.02/.24	3.95/2.25	5.64/3.25
0	1.0/.65	1.95/.15	1.68/.88	2.48/.19	12.19/8.9	12.27/8.08
50	1.84/.32	1.41/.20	3.50/2.52	1/68/.29	13.80/6.24	5.23/1.19
00	2.05/.26	1.57/.36	4.36/2.35	1.93/.58	13.95/3.86	5.55/1.63

EOTS-FACT

req. (Hz)	FOM 70 RD 200	FOM 70 RD 700	FOM 75 RD 200	FOM 75 RD 700	FOM 80 RD 200	FOM 80 RD 700
5	1.15/.49	1.72/.40	2.20/1.26	1.96/.49	6.5/3.53	7.42/2.17
0	1.22/.59	1.72/.40	2.46/1.4	1.90/.60	8.78/7.28	8.11/3.85
50	1.31/.72	1.75/.75	2.56/1.59	3.07/1.19	10.15/9.65	7.13/2.40
00	1.25/.62	1.75/.75	2.56/1.86	3.07/1.19	8.79/7.68	7.13/2.40

ACTUAL BT-FACT

req. (Hz)	FOM 70 RD 200	FOM 70 RD 700	FOM 75 RD 200	FOM 75 RD 700	FOM 80 RD 200	FOM 80 RD 700
25	.98/.6	1.26/.49	1.7/.98	2.02/.93	4.26/2.46	11.35/3.18
50	.95/.59	1.26/.49	1.81/.93	2.02/.93	4.38/2.45	11.35/3.18
150	1.07/.60	1.26/.49	2.1/.77	1.31/.51	5.57/2.86	10.21/2.5
300	1.17/.73	1.26/.49	2.45/1.29	2.02/.93	7.21/3.79	10.21/2.5

TABLE I

Mean and standard deviation of the median detection range (MDR) for all phases of the analysis.

ODT

Freq.	FOM 70 RD 200	FOM 70 RD 700	FOM 75 RD 200	FOM 75 RD 700	FOM 80 RD 200	FOM 80 RD 700
5	(.5-2.0)	(1.0-1.5)	(.5-3.5)	(1.5-2.5)	(2.5-10)	(3-7.5)
0	(.5-2.0)	(1.5-2.0)	(1-4.0)	(2.0-3.0)	(3-25.0)	(4-25.0)
50	(1.0-2.5)	(1-1.5)	(2-12.0)	(1.0-2.5)	(7-25.0)	(4.8.0)
00	(1.0-2.5)	(1-2.5)	(2-5.0)	(1.5-3.5)	(8.23.0)	(4-9.0)

EOTS

Freq.	FOM 70 RD 200	FOM 70 RD 700	FOM 75 RD 200	FOM 75 RD 700	FOM 80 RD 200	FOM 80 RD 700
25	(.5-2.5)	(.5-3.0)	(.5-8.0)	(.5-6.0)	(1.5-17)	(4-16)
50	(.5-3.0)	(.5-3.0)	(.5-8.0)	(.5-10)	(2-25.0)	(4-25)
150	(.5-3.0)	(.5-3.0)	(1-8.0)	(.5-6.0)	(2-29.0)	(4-16)
300	(.5-3.0)	(.5-3.0)	(1-8.0)	(.5-6.0)	(3-27.5)	(4-16)

BT

Freq.	FOM 70 RD 200	FOM 70 RD 700	FOM 75 RD 200	FOM 75 RD 700	FOM 80 RD 200	FOM 80 RD 700
25	(.5-2.5)	(.5-2.5)	(.5-2.5)	(1-5.0)	(1.5-13.0)	(5-16)
50	(.5-2.5)	(.5-2.5)	(.5-2.5)	(1-5.0)	(1.5-13.0)	(5-16)
150	(.5-2.5)	(.5-2.5)	(.5-2.5)	(1-5.0)	(2.5-13.0)	(6-13)
300	(.5-2.5)	(.5-2.5)	(.5-2.5)	(1-5.0)	(2.5-13.0)	(6-13)

TABLE II

Minimum and maximum values (range) of the median detection range (MDR) for all phases of the analysis.

for the most part) that as depth increased from 200 feet to 700 feet to 12,770 feet, acoustic stability increased. That is, the variance of MDR, both quantitative in the form of statistics, and qualitative in the form of a time series, was reduced. For the near-bottom mounted receiver, regardless of the input thermal profile, the results were identical for all three experiments at a constant FOM and were virtually independent of frequency. This indicated that the model system was insensitive to the near-bottom mounted receiver for a 300 foot source.

Overall, the analysis of the three systems showed that the model systems were sensitive to (1) FOM (2) frequency (3) source/receiver depth and (4) thermal profile. Although this information is not new, the analysis gives a good insight into the magnitude of the variance of the parameters. Single profile analysis and snapshot analysis done in the past yielded the information that the FACT model was sensitive to many parameters [Harvey, 1973]. A time series analysis yields valuable information in an attempt to find some operational limits of variability, even if just for a single point in the ocean. For the entire analysis, the limits of acoustic variability are seen in Tables 1 and 2. Table 2 gives the range of values of the MDR. In Table 1 the numbers indicate the mean MDR and the standard deviation of the mean. Note that the statistics are insignificant due to the very limited

data set. However when viewed together with the graphical analysis, a much better insight to the variability is gained.

A further perspective of acoustic variability was gained by doing a qualitative analysis of the three data sets. The first data set analyzed was EOTS-FACT. Very simply, the propagation loss profiles obtained were overlayed in a daily sequence on a light table. The envelope of the propagation loss profiles spanned 10 dB. If the structure (interference patterns) of the propagation loss curves was considered, the difference was 15 dB or more. This acoustic variability in the basic acoustic profile was startling considering that it occured in a 10 day period.

Following the same procedure with the ODT-FACT output, the second experiment, the envelope of the propagation loss curves spanned no more than 5-6 dB; 8 dB when the structure was considered. The envelope was less than (3-4 dB) at the 700 foot receiver.

For the BT-FACT reference data, the envelope for the propagation loss curves was remarkably stable (2-4 dB), and even more so at depth. This analysis supported the premise that the ocean was relatively stable over a synoptic period for passive acoustic frequencies.

Analysis, both qualitative and quantitative shows that (1) EOTS-FACT and ODT-FACT indicate more acoustic variability than direct environmental (BT) input and (2) the acoustic

measure of effectiveness for the entire analysis (MDR) varied with FOM, frequency, and receiver depth, in that order.

Since the FACT model was not operator tuned throughout the analysis, but acted much like a black box, then the acoustic differences observed should be attributable to the input thermal structures.

B. THERMAL STRUCTURE COMPARISON

Because of the large amount of acoustic variance evident between direct BT input and model thermal structure inputs, and given the premise that the FACT model was unchanged throughout all three experiments, it was logical to assume that acoustic differences in the experiment resulted from differences in the input or model-produced thermal profiles.

Figures 73-75 contrast the time series changes of the three thermal profile inputs as well as the corresponding sound velocity profiles. It is evident that the actual BT's input displayed the widest envelope above the thermocline and that there was a steep below layer gradient structure. The ODT thermal structure was initiated with an isothermal profile with no dramatic below layer gradient structure. The ODT model adjusted to the boundary conditions, generating a significant transient thermocline in a synoptic period of five days (Fig. 76).

The EOTS thermal structure (Fig. 74) was a blending of climatology with actual bathythermographs. Observe that the resulting profile displays changes both above and below the

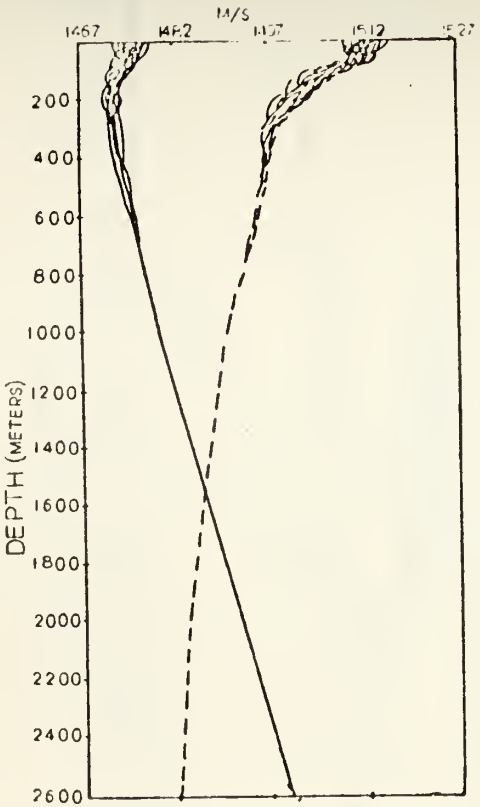


Figure 73

Thermal structure and sound velocity profile envelope for the BT-FACT system.

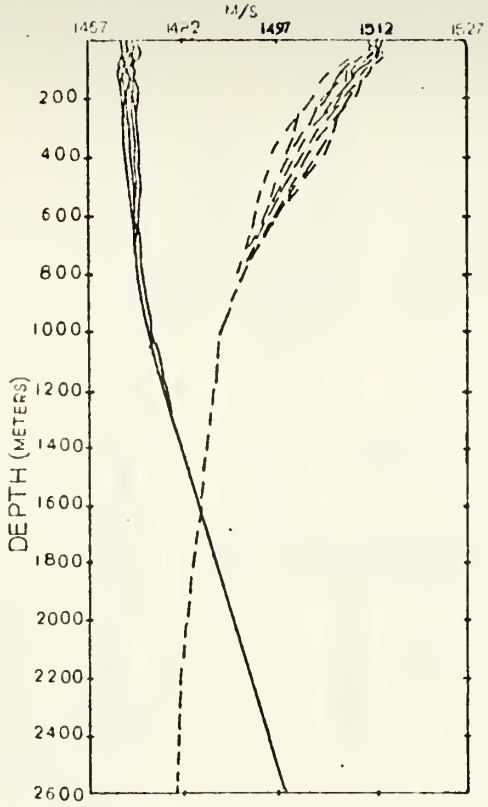


Figure 74

Thermal structure and sound velocity profile envelope for the EOTS-FACT system.

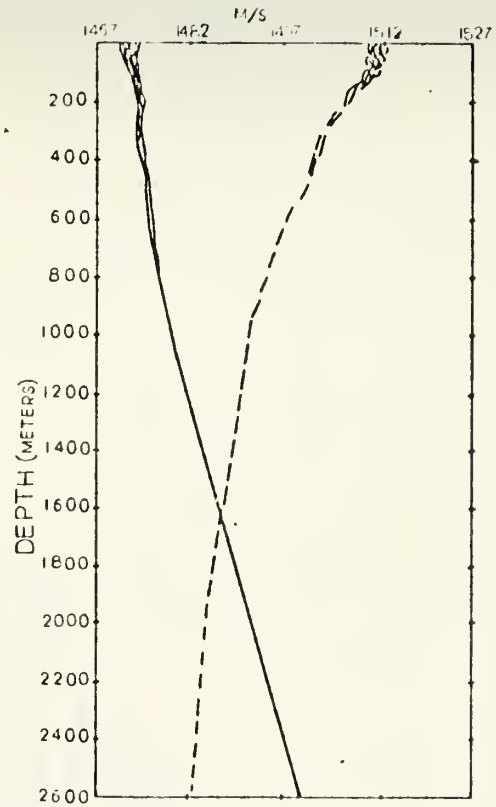


Figure 75

Thermal structure and sound velocity profile envelope for the ODT-FACT system.

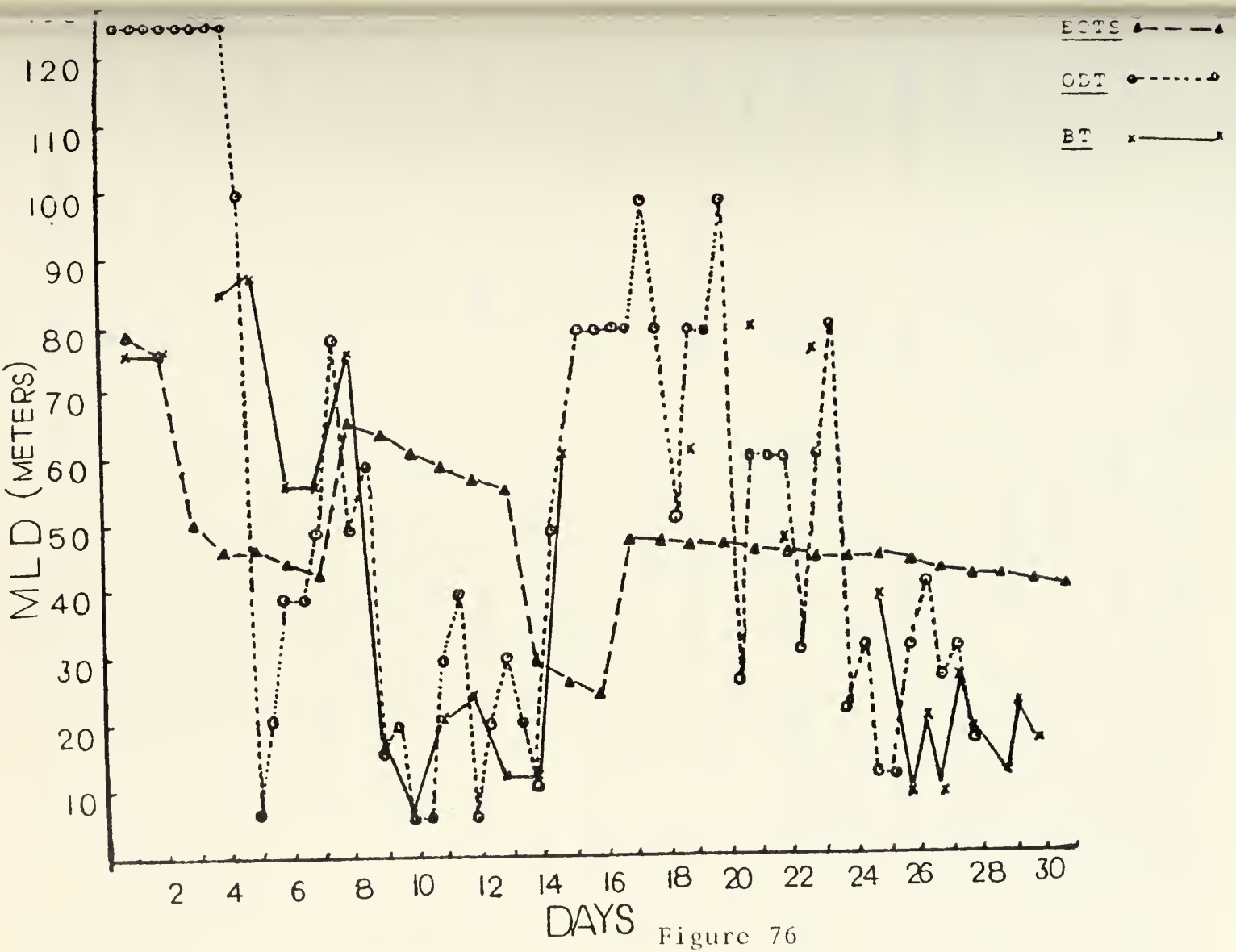


Figure 76

Mixed layer depth versus time for the BT-FACT, ODT-FACT and EOTS-FACT systems.

MLD but that the below layer gradient structure is not nearly as steep as the BT below layer gradient structure (Fig. 73).

1. Mixed Layer Depth

Comparison of the mixed layer depth was made instead of sonic layer depth or primary layer depth because the mixed layer depth was the only parameter implicit or readily obtainable in all three thermal structures. Comparison of mixed layer depth versus time (Fig. 76) for the entire analysis showed that EOTS had the least amount of variance and that the ODT and actual BT mixed layer depths correlated very well, showing similar marked variance. Comparing the EOTS mixed layer depth to the ODT or actual mixed layer depth, a negative correlation (-.12) existed for the time series analysis. Figures 77 through 79 visually depict the cross correlation as the ODT mixed layer depth is advanced one day at a time. Figure 76 yielded insight into a visual trend analysis and showed as the actual layer depth increased or decreased, so did the ODT mixed layer depth after the five day initialization process. Moreover, as the ODT layer depth was moved forward in time, one day at a time (Figs. 76-79) the correlation increased from .21 on the first day to a maximum of .41 on the second day, then dropped off again with any further time lag. This was an initial indication that the EOTS mixed layer depth lagged the ODT and BT mixed layer depths by approximately two days.

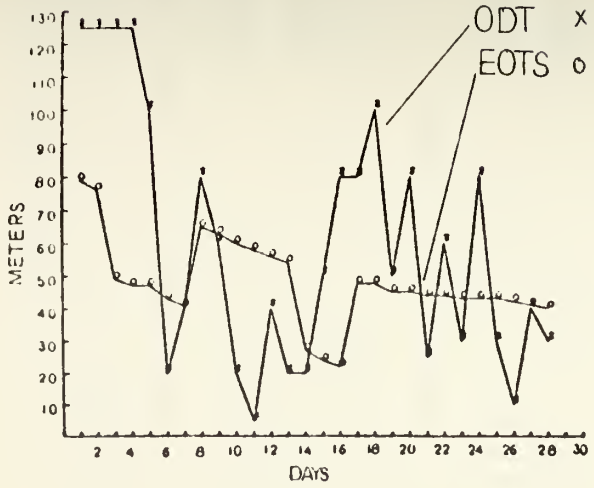


Figure 77

Mixed layer depth versus time: Comparison of ODT to EOTS, ODT shifted forward one day.

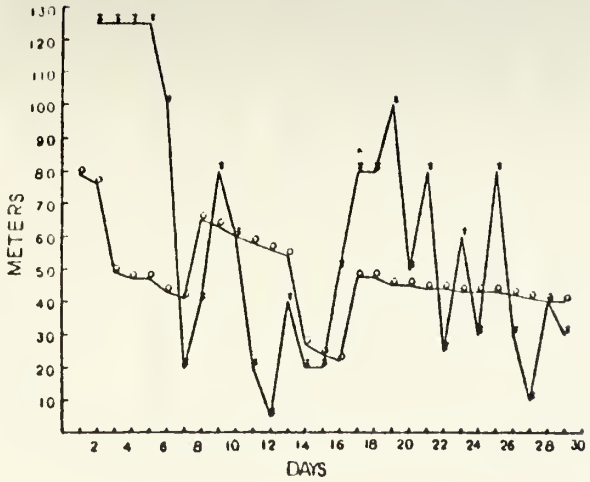


Figure 78

Mixed layer depth versus time: Comparison of ODT to EOTS, ODT shifted forward two days.

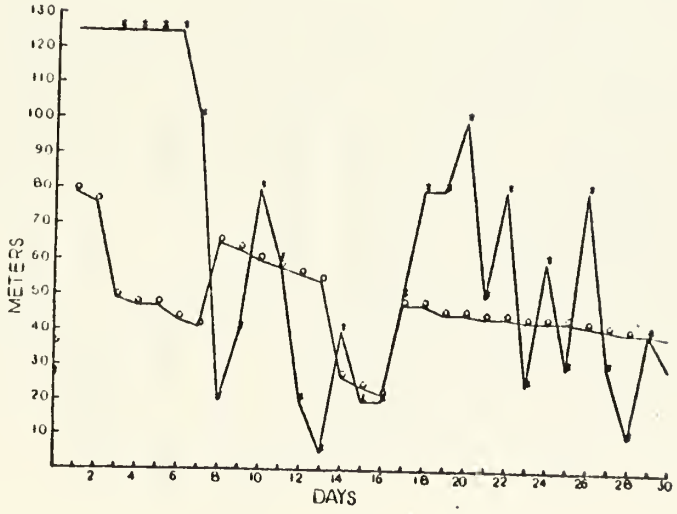


Figure 79

Mixed layer depth versus time: Comparison of ODT to EOTS, ODT shifted forward three days.

A point by point comparison of the BT layer depth with the EOTS layer depth (Fig. 76), revealed even more information. Investigation revealed that the actual BT's used in the analysis by FNOC were the only inputs to the EOTS system for 50^{o}N, 145^{o}W (OWS Papa) for the period of the experiments (1-30 May). Although OWS Papa is not a grid point (Fig. 80) it is very close to one of the grid points, and because of the number of BT's input from OWS Papa, the station readings will always dominate temperature values at that grid point. During the period 16-18 May, no BT's entered the EOTS system at OWS Papa (Fig. 76). Analysis of the layer depths showed that on 17 May, the EOTS layer depth deepened from 22 meters to 46 meters. Assuming that no other BT influenced the deepening of this layer, it was a result of the actual BT taken on the 15th of May. The period 17-20 May on the EOTS curve (Fig. 76) corresponds to "no input" or no change in the actual BT because there was no input BT during the period 16-18 May 1980.

Much of the thermal layer depth discrepancy can be attributed to this apparent "real-time" lag. This apparent lag may not be statistically significant and not necessarily indicative of the EOTS process in general. However, further investigation is warranted. Other parameters, sea surface temperature and below layer gradient, must also be considered in the final analysis.

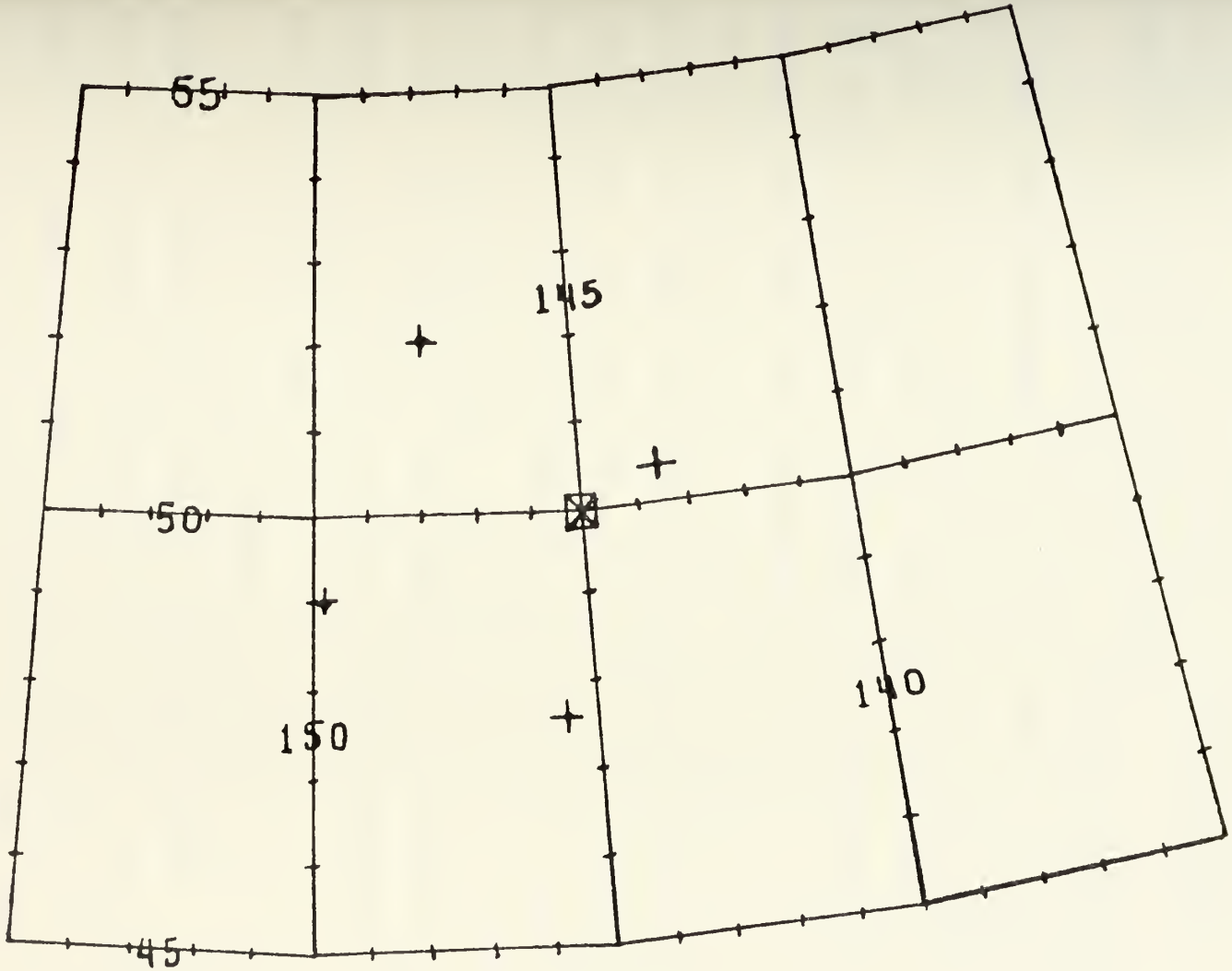


Figure 80

EOTS grid structure location
in comparison to OWS Papa.

2. Event Analysis

The final Surface Analysis Charts were obtained from the National Weather Service in order to attempt to correlate atmospheric forcing with a change in the layer depth. The analysis yielded the following results.

The period from 9 May to 14 May was characterized by the lowest sustained winds of the month, from 5 kts to 15 kts (Fig. 3). During this period, two light storms (wind events < 15 kts) passed over OWS Papa. The actual BT and the ODT mixed layer depths indicated a layer deepening with storm passage and then a layer shallowing as heat was influxed downward across the surface (Fig. 76). The MLD for this period (9-14 May) was characteristically shallow as was expected for a net heat gain and with little vertical mixing. The EOTS thermal layer depth during this period showed a gradual layer shallowing. The EOTS system was insensitive to the wind events as it was dominated by the EOTS climatology and by the net increase in the sea surface temperature (SST) during the period (Fig. 81).

During the second observation period (14-20 May), the most intense wind action of the month occured. The region was characterized by winds from 15 to 30 kts, with sustained winds in excess of 15 kts (Fig. 3). Two strong wind events accompanied by fronts exemplified by very tight low pressure gradient systems swept through the area. On the 14th of May

(Fig. 76), a dramatic layer deepening was predicted in the ODT model and confirmed by the actual BT. Apparently, no BT's were taken at OWS Papa because of the intense storm action during 16-18 May and analysis of the weather charts showed the observation ship tracking away from the front. At the same time that the BT showed a dramatic deepening of the mixed layer, the EOTS layer depth was still shallowing (Fig. 76), probably in response to actual BT's from the 12th-14th of May. Finally, on the 16-17th of May, the EOTS layer depth showed a deepening of the mixed layer, apparently in response to the BT on the 15th of May.

The event analysis showed that the BT mixed layer depth and the ODT mixed layer depth were very responsive to environmental forcing while the EOTS system cannot take advantage of meteorological information.

3. Sea Surface Temperature (SST)

The lag found in the EOTS mixed layer depth was not evident in the sea surface temperature (SST) analysis. Moreover, the EOTS SST was very representative of the actual SST throughout most of the period (Fig. 81). The ODT sea surface temperature was very similar in trend to the actual SST and was off in absolute temperature value due to the fact that the initialization SST for the ODT model was quite different ($.5^{o}C$) from the actual SST.

4. Below Layer Gradient

The differences in mixed layer depth in the analysis accounted for some of the acoustic differences. However the

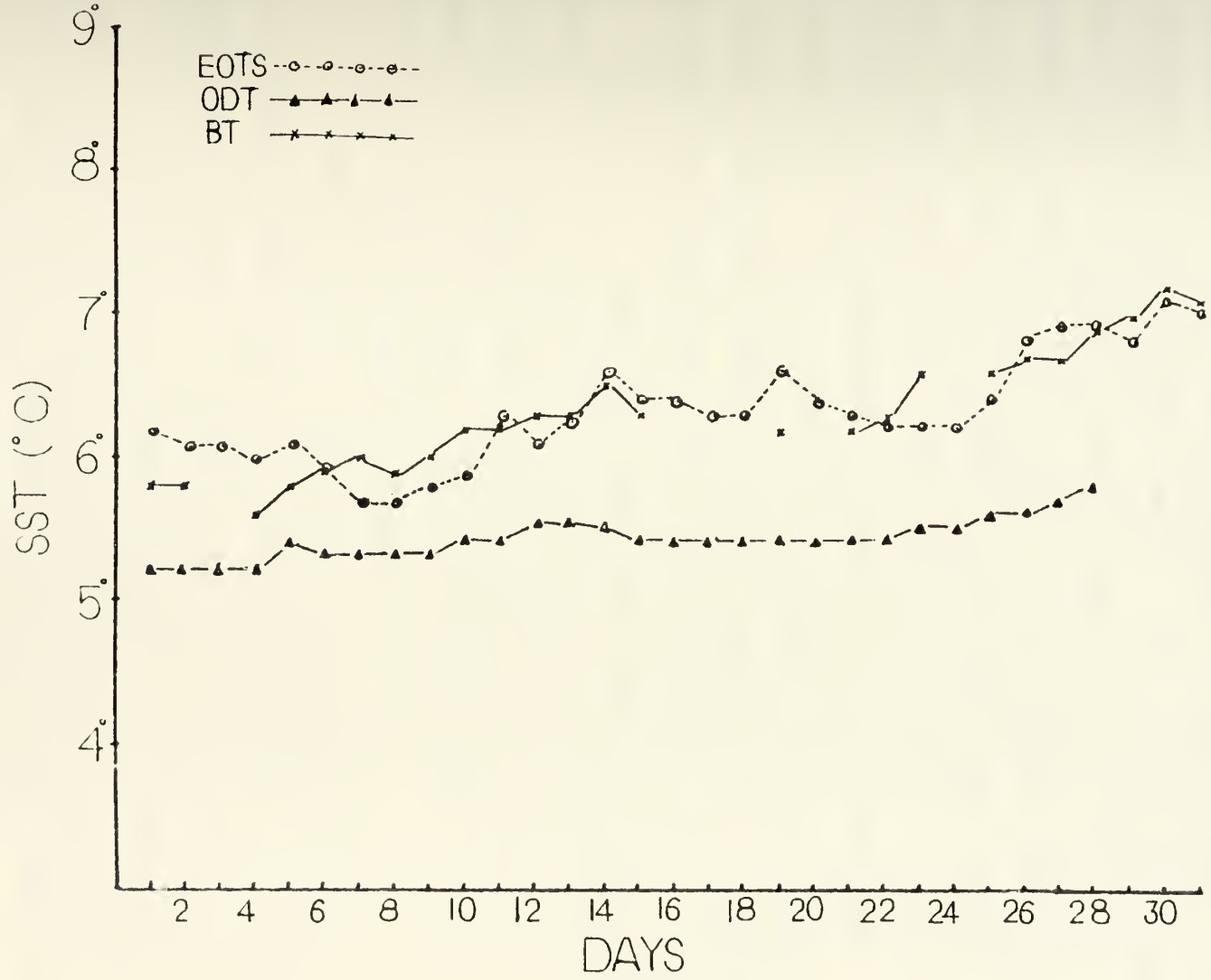


Figure 81

Sea surface temperature versus time: Comparison of ODT and EOTS SST to the BT SST.

below layer gradient structures of the three model systems were also very different and an analysis was attempted.

Figure 82 shows an average below layer gradient structure in a time series analysis for each model system referenced to the BT-FACT system. The average below layer gradient was measured from the base of the mixed layer to a depth of 200m for each system. The ODT model showed the most stability and least variance of the below layer gradient as was expected since the model was only a function of vertical mixing processes between the surface and the permanent thermocline. The BT showed the greatest variance and greatest range of gradient value, probably largely due to vertical motion associated with tidal-period internal waves. Also a factor may be "apparent advection" due to changes in the position of the ship. The EOTS average below layer gradient structure showed a much greater variability than did the ODT model, but it was still markedly different from the measured BT below layer gradient structure.

Another way of looking at the gradient structure in an attempt to show more of a trend analysis was to compare the three systems by looking at the average gradient from the sea surface to 100 meters (Fig. 83). The EOTS gradient structure in this representation is closer to the observed structure. Also, one can see a lag in the EOTS gradient structure of 1-3 days as compared to the BT gradient (Fig. 83).

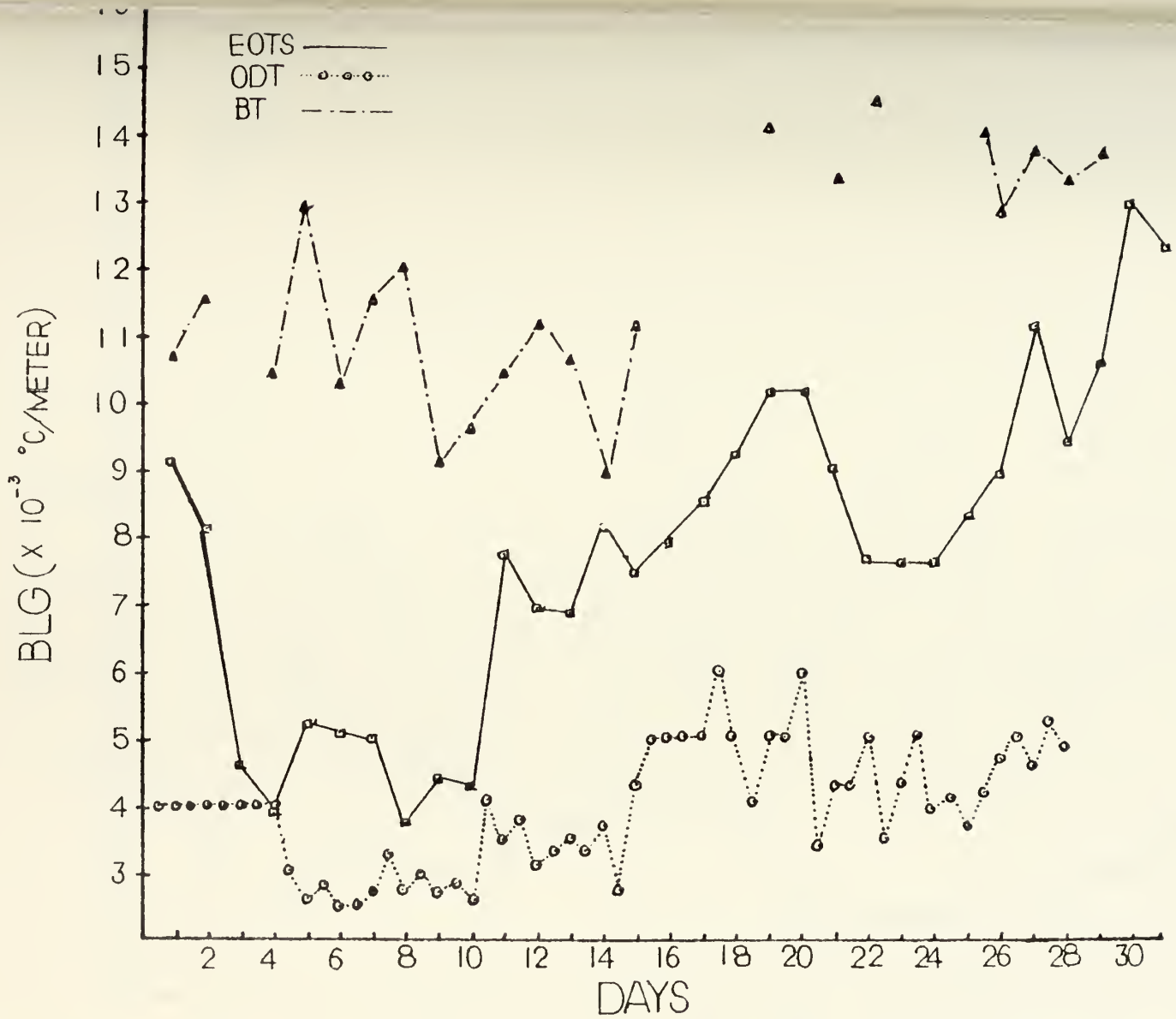


Figure 82

Below layer gradient (measured from mixed layer to a depth of 200 meters) versus time: Comparison of ODT and EOTS with the actual BT.

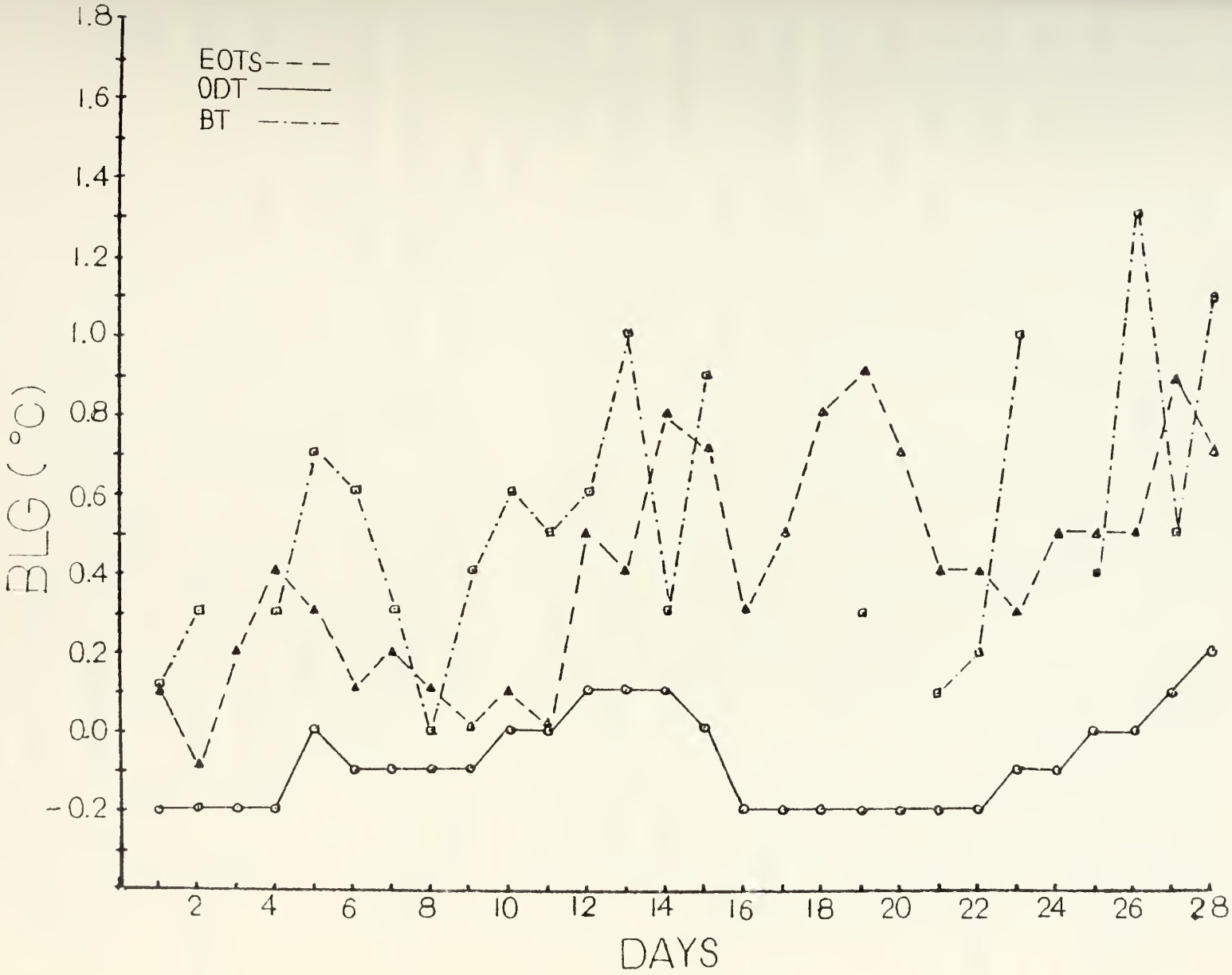


Figure 83

Below layer gradient (measured from the surface to 100 meters) versus time: Comparison of ODT and EOTS with the actual BT.

The ODT model gradient changed more noticeably but still did not treat changes below the MLD.

A most interesting perspective of the below layer gradient structure is gained by overlaying the thermal profiles for each system for the entire month. By doing this, the BT's show a very strong gradient below the mixed layer, extending to beyond 200 meters in depth. This strong gradient structure (Fig. 73) persisted for the entire month. The actual thermal gradient structure resulted in a subsurface duct in the corresponding sound velocity profile (Fig. 73) measuring from 30 meters to over 300 meters. The ODT model, because it was not initialized with any significant gradient structure and because it was intended to model only upper ocean mixing processes, did not show any subsurface duct (Fig. 75). In fact, the ODT thermal structure was basically half channel.

The EOTS sound velocity profile (Fig. 74) showed a very limited subsurface duct. The difference in the gradient structure of EOTS as compared to the observed profile was over $1.5^{o}C/100m$. The BT showed a very strong gradient structure between 100-200 m for the entire month that was never "seen" by the EOTS system. Figures 82 and 83, a graphical analysis of the below layer gradients using two different depths, indicated that the EOTS gradient structure was closer to the BT gradient structure when the gradient was measured to 100 meters instead of 200 meters. Much of the acoustic

discrepancies between the three model systems resulted from differences in the below layer gradient structure. The gradient structure manifested itself in the sound velocity profiles as characteristically half channel for the ODT model, some surface ducting for the EOTS model, and subsurface ducting for on-station BT conditions.

In review of figures 73-75, observe that for the ODT and BT profiles, the major variance occurs above 100 meters while for the EOTS profiles, the major variance occurs near 400 meters. Again, the effects of the below layer gradient structure are seen in the corresponding sound velocity profiles. Figure 84 contrasts the "mean" thermal profile and sound velocity profile. This is done in order to better show the basic differences in the structures. The mean EOTS thermal profile is markedly different in the structure of the below layer gradient. Moreover the variability of the profile at 400 meters is very large. While both the ODT and BT thermal profiles show synoptic changes from 200 to 400 meters, the EOTS thermal structure undergoes changes to below 600 meters.

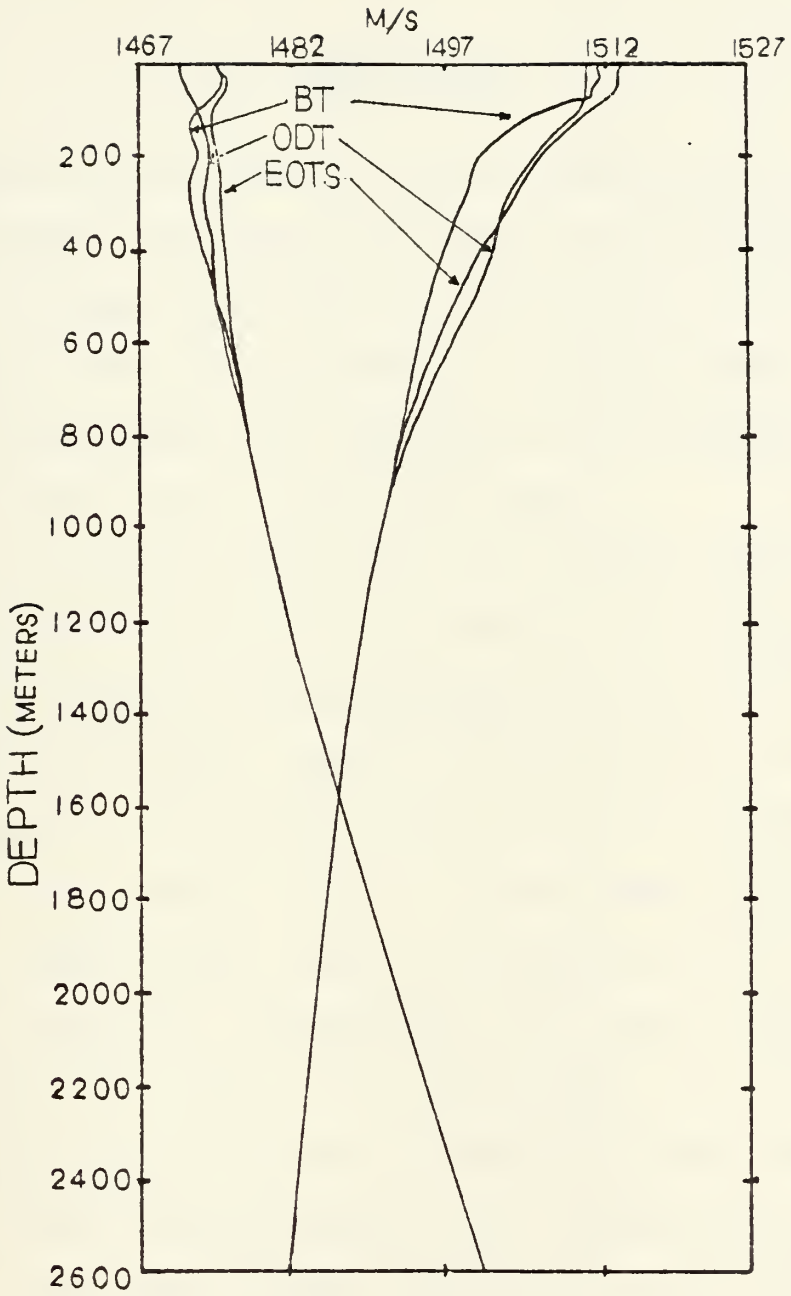


Figure 84

"Average" thermal structure and sound velocity profiles for May 1980, for BT, ODT, and EOTS analyses.

V. CONCLUSIONS

An indepth acoustic analysis was accomplished in order to provide insight into the variability and sensitivity of information received by operational fleet units. Since no actual acoustic data was available as a ground truth, three independent experiments were run using three different thermal structures input to the FACT model.

Subjective acoustic differences between the three systems were examined and the acoustic variability of each system was observed. The merged bathythermograph (BT) served as the reference for the analysis and was as close to the "truth" as was obtainable. Examination and analysis of the data, both thermal and acoustic, led to the following conclusions.

(1) The model systems analyzed indicated more acoustic variability than direct environmental (BT) input supports (Figs. 85, 86). The time series methodology more readily yields insight into the acoustic dynamics of the ocean. While the BT-FACT system displayed only moderate acoustic variability, both model systems (EOTS-FACT and ODT-FACT) indicated much more day-to-day acoustic variability than did the reference system, BT-FACT (Figs. 85,86).

(2) The acoustic variability of MDR was a function of figure of merit, frequency, and depth of the source and

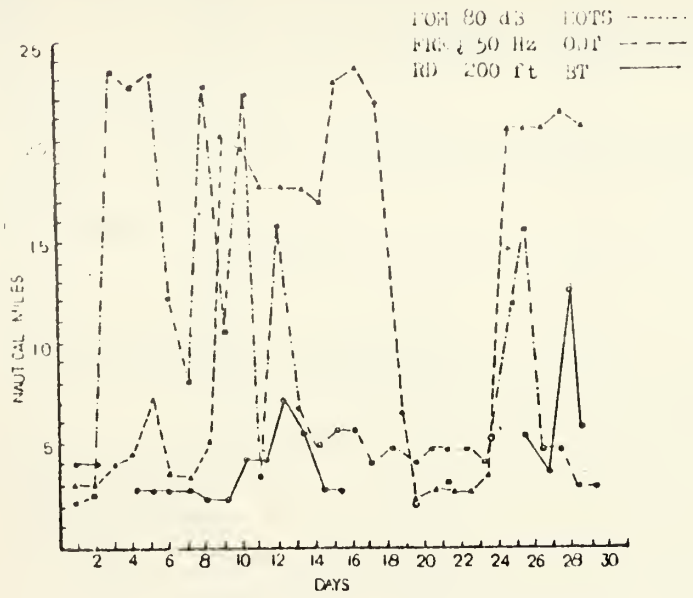


Figure 85

MDR versus time: Comparison of EOTS-FACT and ODT-FACT to BT-FACT for an FOM of 80 dB at 50 Hz, for a RCVR depth of 200 feet.

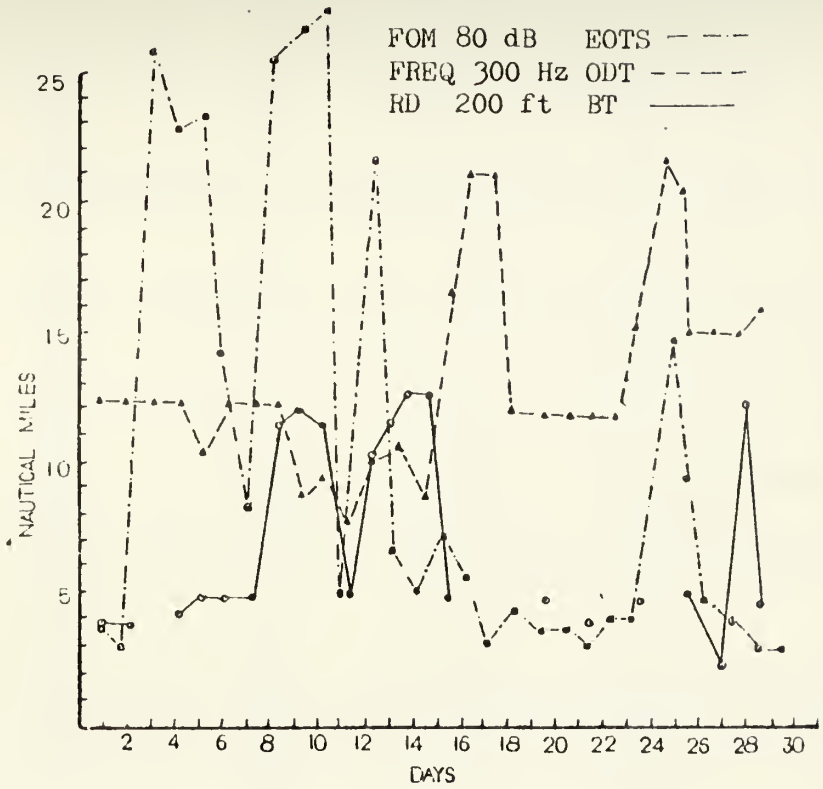


Figure 86

MDR versus time: Comparison of EOTS-FACT and ODT-FACT to BT-FACT for an FOM of 80 dB at 300 Hz, for a RCVR depth of 200 feet.

		EOTS		BT		ODT	
		50 Hz	300 Hz	50 Hz	300 Hz	50 Hz	300 Hz
200 FOOT RECEIVER DEPTH	FOM 75	2.46±1.42	2.56±1.46	1.81±.93	2.45±1.29	1.68±.88	4.36±2.35
	FOM 80	8.78±7.28	8.79±7.68	4.38±2.45	7.21±3.79	12.19±8.9	14.43±4.47
700 FOOT RECEIVER DEPTH	FOM 75	1.9±.60	3.07±1.14	2.02±.93	2.02 ±.93	2.48±.19	1.93±.58
	FOM 80	8.11±3.85	7.13±2.40	11.35±3.18	10.21±2.5	12.27±8.07	5.55±1.67

TABLE III

Mean and standard deviation of the median detection range (MDR) for selected phases of the analysis.

receiver. The limits of variability are shown in Table 3 which gives the mean and standard deviation for selected representation cases.

(2a) As FOM was increased both the mean MDR and standard deviation increased regardless of the model system chosen for analysis.

(2b) Frequency related conclusions are difficult to generalize because of (1) the interdependencies between FOM and receiver depth and (2) the sensitivity of frequency to the algorithms in different acoustic models. As the frequency was increased from 50 Hz to 300 Hz at the 200 foot receiver, the mean MDR increased for all cases and the standard deviation increased for all cases except the ODT-FACT system at 300 HZ and a figure of merit of 80 dB. At the 700 foot receiver, as the frequency was increased from 50 Hz to 300 Hz, the results were displayed in Table 3 for all three analyses.

(2c) For most of the analysis, as the receiver depth was changed from 200 feet to 700 feet (source depth was held constant at 300 feet) the standard deviation of the mean MDR decreased, indicating less acoustic variability as receiver depth is increased. When the absolute standard deviation increased (BT-FACT case), the absolute value of MDR also increased significantly such that the overall variability actually decreased. As an example (Table 3) for 50 Hz at 80 dB FOM for the BT case, the MDR is 4.38 ± 2.45. at the 200 foot receiver depth. At the 700 foot receiver depth for the same conditions, the MDR is 11.35 ± 3.18. If one

compares the ratio of the standard deviation of the mean MDR to the MDR, for the 200 foot receiver, the value is .56. For the 700 foot receiver, the value is .28 which indicates that the overall variability has decreased.

(3) For the entire analysis, much less acoustic variability was reflected at the 700 foot receiver at all frequencies regardless of FOM. Since the upper layers of the ocean reflect more rapid changes, more variability was expected at the shallow receiver (200 feet) as was demonstrated throughout the analysis. This conclusion suggests a depth dependence in the modeling process to the time scale for retaining BT measurements in the EOTS-FACT system. Perhaps weighting BT measurements differently with depth in the modeling process and retaining BT's in the system for longer than the present five day period would improve the thermal representation of the below layer gradient structure.

(4) Mixed layer depth (MLD) appeared to be a good indicator of the effects of atmospheric forcing. As shown in figure 76, the ODT mixed layer depth was a function of the time history of wind speed and solar radiation. The ODT mixed layer depth corresponds very well to the reference BT mixed layer depth in that the trend of the model predicted MLD is almost identical to the trend of the actual BT mixed layer depth. The effects of frontal passage and strong wind events is evidenced in both the ODT mixed layer depth and the BT mixed layer depth.

(5) There were major model limitations in depicting the thermal structure completely and accurately as compared to the observations. The most notable deficiency in modeling the thermal structure was indicated in the representation of the below layer gradient between 100 meters and 200 meters. The inability to accurately represent the thermal profile was the major contributor to the acoustic differences, between the reference system and the model system.

(6) The fleet operational model system (EOTS-FACT) analysis indicated that there was a possible deficiency in its ability to accurately represent a real-time analysis. The apparent two day lag in the EOTS mixed layer depth was further evidenced in the event analysis.

APPENDIX A

A. OPERATIONAL APPLICABILITY

There were a number of lessons learned during the analysis that could greatly impact the operational user.

1. As was stated earlier, the ability to accurately depict the thermal profile is most important. Accuracy and resolution of BT's is essential.

2. The operational user must be aware of the acoustic variability possible as the figure of merit is increased. This point is even more important when uncertainty of source level (SL) or ambient noise (AN) exists. Acoustic variability of even 5 dB can have dramatic effects as shown throughout the analysis.

3. Frequency and depth variations are important, but not to the extent that uncertainty in the figure of merit should be overshadowed. Overall, the higher frequencies (150-300 Hz) showed more day-to-day acoustic variability than the lower frequencies (25-50 Hz) regardless of receiver depth. There was more acoustic variability at the shallow receiver depth as expected.

4. The emergence of sub-surface ducts, a result of the below layer gradient, was important because they account for part of the acoustic differences between the actual BT and model generated thermal structures.

5. Real-time analysis is of the utmost importance. Perhaps on-board processing should be used with direct environmental (BT) input. Without a fleet operational prediction capability of both thermal and acoustic parameters, "real-time" analysis becomes even more important.

6. The acoustic measure of effectiveness (MDR) used throughout the analysis is utilized as a tactical sonobuoy spacing parameter in the ASW localization or tracking phase. For many patterns, sonobuoy spacing is based on (MDR). If the MDR is between two and four miles, pattern spacing will be between three and six miles. If the MDR is between ten and fifteen miles, then the respective pattern spacing could be fifteen to twenty-three miles. It is evident that if the model systems predict more variability than is actually present in the oceanic thermal structure, then the output acoustic product could manifest itself in inaccurate sonobuoy spacing. The end result would most likely be waste of sonobuoys if the modeled MDR is much less than the actual MDR and lost contact if the modeled MDR is a lot greater than the actual MDR.

B. MODELING APPLICABILITY

Aside from the analysis previously covered, there were a few very important facts that emerged. It is imperative that the capability to predict be present for thermal and acoustic modeling from a military standpoint, as the value of real-time

analysis cannot be overemphasized. This treatment of the data showed that there were both thermal and acoustic model differences when dealing with passive systems at low frequencies (below 300 Hz). Real-time analysis and prediction capabilities become even more important when dealing with active systems at higher frequencies.

1. Both thermal and acoustic models should be designed and implemented with the operational user in mind. Model capabilities and parameters should be expressed in operational terms.

2. Sensitivity analyses should be conducted on fleet operational model systems prior to their acceptance in order to place variability limits on operationally important acoustic performance parameters.

3. Actual operational measurements must be compared to model system outputs on a continual basis to ensure the quality and accuracy of model systems.

4. Time series analysis gives a better measure of the acoustic variability of the model systems than snapshot or single look analysis. Models should not only be compared and contrasted to one another based on a single look. Rather, the model should be evaluated on its ability to accurately represent the dynamics of the ocean.

5. Modeling the mixed layer depth (MLD) should be accomplished by using atmospheric forcing so that storm action and wind mixing events (the physics of the ocean)

can be adequately represented.

6. The modeling of below layer gradient can be improved. In the present operational system (EOTS) there was evidence of tremendous variation in the below layer gradient structure (from 100 meters to 500 meters), which supposedly undergoes changes over the long term. Investigation into selectively weighting the below layer parameters as well as retaining BT information in the system for longer periods (greater than five days) of time is warranted. Also, the capability to represent or account for subsurface ducts must somehow be accurately modeled.

7. The ability of the present operational system (EOTS-FACT) to produce real-time information is somewhat questionable. Further investigation into this capability is warranted. Perhaps the time interval when the BT is taken to when it enters the computer system can be shortened. Moreover, future modeling systems should provide a prediction capability.

The conclusions drawn and the lessons learned should be reviewed with the understanding that there are inherent errors in the accuracy of the data due to physical and model limitations. Moreover, the entire analysis was done for a single point (OWS Papa) and for a single month (May 1980). Another caution is that if a different acoustic measure of effectiveness (CZ, etc.) had been used, additional constraints and possibly different results would have been observed. Even with the above restrictions, valuable insight is gained

into the variability of coupled mixed-layer acoustic model systems. Both theoretically and practically, this study has demonstrated possible deficiencies in fleet operational model systems as well as indicate the present state of the art in modeling the ocean thermally and acoustically.

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